# COMPARATIVE STRESS DISTRIBUTION OF DIFFERENT IMPLANT DESIGNS IN BONE:

# A 3-D FINITE ELEMENT ANALYSIS

*Dissertation submitted to*

**The Tamil Nadu Dr. M.G.R. Medical University**

*In partial fulfilment of the degree of*

**MASTER OF DENTAL SURGERY**

**BRANCH I**

**PROSTHODONTICS AND CROWN & BRIDGE**

**2014-2017**

# CERTIFICATE

This is to certify that the dissertation entitled "**Comparative stress distribution of different implant designs in bone: A 3-D Finite element analysis**" is a bonafide record of the work done by Dr. Vivek.B. Chandran, Post graduate student during the period 2014-2017 under my guidance and supervision. This dissertation is submitted in partial fulfilment of the requirements for the award of MASTER OF DENTAL SURGERY IN, BRANCH I (PROSTHODONTICS AND CROWN AND BRIDGE) under THE TAMIL NADU Dr.M.G.R MEDICAL UNIVERSITY, CHENNAI. It has not been submitted (partial or full) for the award of any other degree or diploma.

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This is to certify that the Research Protocol Ref. No. **SMIMS/IHEC/2015/A/37**entitled "Comparative Stress Distribution of Different Implant Designs in Bone: A 3-D Finite Element Analysis" submitted by Dr. Vivek. B. Chandran, Postgraduate of Department of Prosthodontics and Implantology, SMIDS has been approved by the Institutional Human Ethics Committee at its meeting held on 22nd December 2015.

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# DECLARATION

I hereby declare that this dissertation "**Comparative stress distribution of different implant designs in bone: A 3-D Finite element analysis**" is a bonafide record of work undertaken by me during the period 2014-2017 as a part of post graduate study. This dissertation, either in partial or in full, has not been submitted earlier for the award of any degree, diploma, fellowship or similar title of recognition.

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# ABSTRACT

## Introduction

Development of an ideal substitute for missing teeth has been a major challenge of dental practitioner for millennia. An implant is a medical device which is made from one or more biomaterials, that are intentionally placed in the body either totally or that is partially buried beneath an epithelial surface. Many factors affect load transfer at the bone implant interface such as the type of loading, material properties of the implant and prosthesis, implant geometry, surface structure, implant design quality (diameter and length) and quantity of surrounding bone, and nature of bone implant interface. Insufficient vertical and horizontal bone volume does not allow implant placement particularly in the bone atrophy distal to the mental foramen. In this instance, small-diameter implants may be used where there is not enough bone width in the alveolar ridge; however, large-diameter implants have been proposed to increase the osseo integrated implant interface.

Here using a finite element analysis the stress distribution among four different implant designs were compared and the implant with the most favorable stress distribution in bone was found.

## Aims and Objectives

The aims of the study are to compare the stress distribution of various implant designs in bone using a three dimensional finite element analysis.

The objective of the study is to compare stress distribution among long and short implants and also between cylindrical, tapered and hybrid implant designs. This is to determine which implant design is the most ideal one in distributing stresses in the bone so that it will enhance the stability as well as survival rate of the implant.

**Methodology**

A three dimensional finite element model of the mandible with four different implant designs were modelled based on the measurements of a dried human edentulous mandible using modelling software ‘Solidworks’ and was analyzed for stresses produced in the bone following axial and non-axial biting loads of different magnitude using ‘ANSYS Workbench’.

**Results**

The results of the study indicated that implants with wider diameter have more favorable stress distribution in bone compared to longer implant designs and influence of implant length and taper was not as pronounced as that of implant diameter.

**Summary and Conclusion**

Based on the observations in this study, it was concluded that short implants with wider diameter have more favorable stress distribution compared to other implant designs and could be considered for use with fixed restorations. However further clinical research is suggested in order to prove it as a reliable and successful treatment modality

# *INTRODUCTION*

Dentists and dental specialists employ considerable clinical skills in an effort to cope with the consequences of partial and/or complete edentulism. These consequences are related mainly to partial or total deficits in one or both jaws. As a result, clinical ingenuity has led to many treatment successes with prostheses supported by varying degrees of residual periodontium and/or alveolar bone. The success rate of such prosthesis in a reduced or inadequate residual ridge was a great concern for the prosthodontists till the invention of implants.

Dental implants are artificial tooth replacements that were first developed half a century ago by a Swedish scientist named Per-Ingvar Branemark who once stated that

***"No one should have to die with their teeth in a glass of water beside their bed"***

Implants arose from the patient's need to secure loose-fitting dentures. Since the introduction of the implants in dentistry, they have undergone many engineering enhancements which enabled dentists to expand the implant's usefulness to a wide range of tooth replacement solutions from single tooth replacements to even full mouth rehabilitation and also in maxillofacial prosthesis, though this system has been a revolutionary invention in the field of dentistry, still many cases of implant failures has been reported in literature.

Implant failures has led the dental practitioner to realize that the available knowledge regarding implants is not enough to place an implant, wait for osseointegration and to deliver an aesthetic crown. With the recent researches it is evident that complex biological processes can sabotage even a carefully done implant over time. Therefore strategies to establish and sustain the aesthetics and durability of implants have taken paramount importance.

There are various reasons for implant failure. Primary predictors of implant failure are poor bone quality, chronic periodontitis, systemic diseases, smoking, unresolved caries or infection, advanced age, implant location, short implants, acentric loading, an inadequate number of implants, parafunctional habits and absence/loss of implant integration with the hard and soft tissues. Inappropriate prosthesis design may also contribute to implant failure. The factors which are helpful in implant success rate are the quantity and quality of bone, the patient's age, the dentist's experience, the location of implant placement, length of the implant, axial loading and oral hygiene maintenance. Based on all these factors the implant success takes place.

In recent times, various designs of implants have been created to overcome these failures and to distribute the stress evenly in the alveolar bone which is also a reason for implant compliance. Different types of implants have different effects on the underlying bone and it is important to analyze these designs for its selection in clinical application. To study these stress distribution by various designs of implants, three dimensional finite element analysis (FEA) are carried out which gives us a pre-operative idea regarding the success rate of implant design.

Finite element analysis (FEA) has been used extensively to predict the biomechanical performance of various dental implant designs as well as the effect of clinical factors on implant success. By understanding the basic theory, method, application, and limitations of Finite element analysis in implant dentistry, the clinician will be better equipped to interpret results of Finite element analysis studies and extrapolate these results to clinical situations.

With the emergence of Finite element analysis implant success rates have also gradually increased. The main objective of this dissertation is to compare stress distribution among four different types of implant designs by conducting a three dimensional finite element analysis and to determine which implant is better among these designs in ideally distributing stress into the bone.

## AN INTRODUCTION TO FINITE ELEMENT ANALYSIS

The Finite Element Analysis (FEA) is a computer aided mathematical technique for obtaining approximate numerical solutions to the abstract equations of calculus it predicts the response of physical systems subjected to external influences.

Finite element analysis is a computer aided mathematical technique and will give only mathematical solutions, so the only way a response of a system (physical or biological) can be predicted with a Finite element analysis is to convert the problem from a physical/biological one to a mathematical one and later on the mathematical solutions to the problem can be interpreted into physical/biologic terms.

The four concept used in Finite element modeling are,

**a) System, b) Domain, c) governing equations d) loading conditions**.

The ***system*** is typically a physical object composed of various materials, e.g. solids, liquid, gases or combination of the above.

The ***domain*** of problem is typically the region of space occupied by the system

The ***governing equations*** may be a differential equation, integral equation or a constitutive equation describing the physical properties, & material behavior.

***Loading conditions*** are externally originating forces, temperature, etc. that interact with the system causing the state of the system to change. Load acting in the interior of the domain, i.e. interior load appears as part of governing equation. Loads acting on the boundary of the domain i.e. boundary loads appears in separate equation called boundary conditions.

STEPS IN FINITE ELEMENT ANALYSIS

***Define a specific problem***

- Geometry
- Physical Properties
- Loads

***Input data to program***

- Geometry of domain mesh generation
- Physical properties
- Loads interior and boundary
- Type of output desired

**FINITE ELEMENT PROGRAM**

***Process Output***

- Select type of data
- Generate related data
- Display meaningfully and attractively

In this method domain (structure) of the problem is divided into smaller regions called elements. Adjacent elements touch without over lapping and the there are no gaps between the elements. The shape of the elements are intentionally made as simple as possible, such as *triangles* or *quadrilaterals* in two dimensional domains and *tetrahedra, pentahedra* (wedges or pyramids) and *hexahedra* (bricks) in three dimensions. The entire mosaic like pattern of element is called a *Mesh.* The *Mesh generation* is done by *preprocessors.* In each element the governing equations are transformed into algebraic equations, called *Element Equations*, which are an approximation of the governing equations. Algebraic equations are much easier to work and are relatively easy to solve.

The terms in the element equations are numerically evaluated for each element in the mesh, a process best performed on a computer. The resulting numbers are *assembled* into a much larger set of algebraic equations called the *System equations.* These characterize the response of the entire system so they usually comprise of a very large number of equations, hundreds of thousands. Such huge systems of equations can be solved economically because the matrix of coefficients is *"sparse"*.

Now the boundary conditions are applied which include the boundary loads. These are imposed by modifying the system equations. This involves adding values to existing terms and / or shifting terms from one side of the equations to the other. Both are relatively simple operations.

The system equations are then solved on a computer using conventional numerical analysis techniques that have been popular for many years, having evolved prior to the Finite element analysis.

The final operation, called *post processing* displays the solution to the system equations in tabular, graphical, or pictorial form. Other physically meaningful quantities might be derived from the solution and also displayed.

The ideas that gave birth to the Finite element analysis evolved gradually from the independent contributions of many people in the fields of engineering, applied mathematics and physics. The essential ideas, though, began to appear in publication principally during the 1940s. **Courant's paper in 1943**[1] is a classical one. The name of the method **"finite elements"** first appeared in **Clought's paper in 1960**[1]. Since then Finite element analysis has come a long way through.

In this method, structures are subdivided into nodes and elements which facilitates determination of the structural stiffness and ultimately deflection and stresses (Force =stiffness x Deflection). Material properties such as the **Young's modulus** (modulus of elasticity) and **Poisson's** ratio can be utilized by computer generated analysis to describe the mechanical behavior and induced stresses and of a structure. Calculation of these stresses allows the investigator to determine areas of high stresses of large deformations which could lead to fracture or failure of the structure. A general purpose finite element software provides the necessary tools to perform such analysis for a wide variety of problems without compromising accuracy.

# *AIMS AND OBJECTIVES*

## AIMS:

To compare the stress distribution of various implant designs in bone using a three dimensional finite element analysis.

## OBJECTIVES:

- ✓ To compare the stress distribution in bone under axial and non-axial loading.
- ✓ To compare stress distribution in bone by Short implant and Long implant
- ✓ To compare stress distribution in bone by Cylindrical, Tapered and Hybrid implants
- ✓ To determine which implant design is the most ideal one in distributing stresses in the bone so that it will enhance the stability as well as survival rate of the implant.

# *REVIEW OF LITERATURE*

The basic concept behind a **FINITE ELEMENT ANALYSIS (FEA)** is to sub-divide a body of any shape into simpler geometric shapes or elements. The elements are assembled so that their apices meet to form nodes. When a computer analysis is performed a system of simultaneous equations can be solved to relate all forces and displacements at the nodes. From this, stresses and strain contours can be established for the whole body.

Finite element analysis is an innovative theoretical technique originally proposed by **TURNER et al** (1956)[1] (FORCE= STIFFNESS X DEFLECTION). All structures behave like a spring but the stiffness is difficult to determine. Finite element analysis facilitates determination of the structural stiffness ultimately deflection and stress.

**Siegele D et al (1989)**[2] studied the stress distribution generated by different types of dental implants (cylindrical, conical, stepped, screw-shaped, hollow cylindrical) by means of the finite-element method and concluded that different implant shapes lead to significant variations in stress distributions in the bone and also stated that a fixed bond between implant and bone in the medullary region will be advantageous for uniform stress distribution.

**Matsushita Y et al (1990)**[3] conducted a study to know the effect of diameter of hydroxyl apatite coated implants in distributing the stress in alveolar bone and concluded that an implant with a broader diameter is favorable from the standpoint of stress distribution.

**Sertgöz A et al (1996)**[4] investigated the stress distribution at the bone/implant interface with a three-dimensional finite element stress analysis and stated that the maximum stress occur at the most distal bone/implant interface located on the loaded side and significantly increased with the length of the cantilever and there was no statistically significant change associated with the length of implants.

**Holmgren E P et al (1998)**[5] evaluated the effect of implant diameter variation using a press-fit stepped cylindrical implant type and a press-fit straight cylindrical implant type as osseo-integrated in the posterior mandible and suggested that using the widest diameter implant is not necessarily the best choice when considering stress distribution to surrounding bone and observed that stress is more evenly dissipated throughout the stepped cylindrical implant.

**Stellingsma C et al (2000)**[6] assessed the success of short endosseous implants in combination with an implant-retained overdenture in extremely resorbed mandible and reported a cumulative survival rate of 88% at the end of 8 years and due to the low morbidity of this treatment, it was considered as a better treatment option.

**Winkler S et al (2000)**[7] conducted a study on stability and survival rates of implants of different diameters and lengths for 36 months post-placement and reported that shorter implants had statistically lower survival rates as compared with longer implants.

**Akca K et al (2002)**[8] evaluated the effect of placement of a shorter implant in place of a cantilever extension on stress distribution compared with that of a cantilevered fixed prosthesis in mandibular posterior edentulism and stated that an additional placement of a shorter implant reduces the stress and can be considered as a better treatment option in place of cantilevers**.**

**Iplikcioglu H et al (2002)**[9] compared the effects of diameter, length and the number of implants in stress distribution in the bone, around the implants supporting three unit fixed partial prostheses in the mandibular posterior region and reported that length of the implant did not decrease the stress levels whereas lower compressive and tensile stresses were observed in the bone for wider implant placement.

**Shinichiro T et al (2003)**[10] evaluated the influence of implant dimensions and bone quality on the stress/strain and found out that maximum equivalent stress/strain in bone increases with a decrease in cancellous bone density and screw-type implants showed a decrease in maximum equivalent strain compared to other designs.

**Himmlova´ L et al (2004)**[11] conducted a study to determine which length and diameter of implants would be the best to dissipate stress and concluded that the decrease in stress was the greatest for implants with larger diameter compared to smaller ones and the influence of implant length was not as pronounced as that of implant diameter.

**Lin C-L et al (2005)**[12] evaluated the influence of implant length and bone quality on the biomechanical aspects of alveolar bone-dental implant complex and concluded loading conditions as the most important factor affecting the biomechanical aspects than the bone quality and implant length.

**Petrie C S et al (2005)**[13] analyzed and compared effects of implant diameter, length and taper on calculated crestal bone strains and concluded that if the objective is to minimize peri-implant strain in the crestal alveolar bone, a wide and relatively long, non-tapered implant appears to be the most favorable choice.

**Renouard F et al (2006)**[14] reviewed the literature in order to explore the relationship between implant survival rates and their length and diameter and concluded that the use of a short or wide implant may be considered in sites thought unfavorable for implant success, such as those associated with bone resorption or previous injury and trauma.

**Lehmann R B et al (2007)**[15] evaluated the stress distribution in the cortical bone under different shape of dental implants in cantilever loading using three dimensional finite element analysis and concluded that the use of conical implant in patients with cantilever structure is more indicated when compared with that cylindrical implant.

**Yingying Sun et al (2007)**[16] conducted a study to determine the optimal thread design for an experimental cylindrical implant and concluded that single-thread implant showed the best stress transmission under axial load whereas single-thread and triple-thread implant showed the better stress transmission under bucco-lingual load.

**Baggi L et al (2008)**[17] analyzed the influence of implant diameter and length on stress distribution and overload risk of clinically evidenced crestal bone loss at the implant neck in mandibular and maxillary molar peri-implant regions and concluded that the stress values and concentration areas decreased for cortical bone when implant diameter is increased, whereas more effective stress distributions for cancellous bone were experienced with increasing implant length.

**Danza M et al (2009)**[18] studied the spiral family implants which are inserted in different bone quality and connected with abutments of different angulations using three dimensional finite element analysis and concluded that the spiral family implants can be used successfully in low bone quality cases but a straight force is recommended.

**Guan H et al (2009)**[19] conducted a study to evaluate various bone and implant parameters for their influence on the distribution of Von Mises stresses within the mandible and revealed that an increase in Young's modulus and decrease in cortical bone thickness elevated the stresses within both cancellous and cortical bone whereas increase in implant length reduced the magnitude of stress due to increased surface contact between bone and implant.

**Sartori E A et al (2009)**[20] conducted a study comparing the stress distribution in mandibular overdentures by cylindrical and conical implants placed at the canine region and suggested that conical implants reduced the stresses in peri-implant crestal bone at both loading and non-loading sides compared to cylindrical implants**.**

**Ding X et al (2009)**[21] evaluated the effect of the diameter and length on the stress and strain distribution of the crestal bone around implants under immediate loading and concluded that increasing the diameter and length of the implant decreased the stress and strain on the alveolar crest, but diameter had a more significant effect than length to relieve the crestal stress and strain concentration**.**

**Li T et al (2009)**[22] conducted a study to find out the stress distribution by implants of varying length and diameter in type IV bone under biomechanical conditions and stated that in type IV bone, the implant length is crucial in reducing bone stress and enhancing stability than the implant diameter.

**Arisan V et al (2010)**[23] evaluated the survival rates, peri-implant parameters and the mechanical and prosthetic post-loading complications of Narrow Diameter Implants and concluded that they can be used with confidence where a regular diameter implant is not suitable and also stated marginal bone loss around Narrow Diameter Implants occurred predominantly within 2 years of loading and was minimal thereafter.

**Okumura N et al (2010)**[24] investigated the effect of maxillary cortical bone thickness, implant design and diameter on stress around implants and revealed that regardless of load direction, implant design and diameter, cortical and cancellous bone stresses increased with the decrease of crestal cortical bone thickness.

**Ibrahim M et al (2011)**[25] evaluated the design parameters of dental implants like shape; diameter and length on stress distribution by three dimensional finite element analysis (FEA) concluded that the tapered shape implant design exhibited higher stress levels in bone than the parallel shaped implant design which seemed to be distributing stresses more evenly.

**El-Anwar M I et al (2011)**[26] obtained simplified design equations to better understand implants behavior with the help of 25 different implant designs with gradual increase in diameter and length using three dimensional Finite Element Method and showed that increasing implant diameter and length generate better stress distribution on spongy and cortical bones.

**Mammadzada S et al (2011)**[27] evaluated the effect of abutment and implant shapes on stresses in dental implants and stated that the Von

Mises stress distributions on abutment, implant and cortical bone are clearly affected by abutment, implant shapes and also bigger collars.

**Chizolini E P et al (2011)**[28] discussed the features, indications and biomechanical aspects of short implants and concluded that short implants Osseo integration can be compromised by risk factors that must be controlled to achieve treatment success and the main indication of short implants is to avoid an invasive surgery at atrophic areas of maxilla and mandible.

**Sohrabi K et al (2012)**[29] evaluated the success rate of short diameter implants and concluded that the survival rates for Short diameter implants were similar to those reported for standard width implants and suggested that short diameter implants could be considered for use with fixed restorations and mandibular over dentures.

**Desai S R et al (2012)**[30] evaluated the influence of maxillary cortical bone thickness and material of crown prosthesis on stress distribution at bone–implant interface in single immediately loaded short and wide-diameter implants and concluded that the peri–implant stresses on the cortical bone were reduced for Porcelain Fused to Metal crowns and also stated that short and wide implants can be placed in D4 bone quality with thin cortical bone under immediately loading protocol using Porcelain Fused to Metal crowns.

**Saluja B et al (2012)**[31] evaluated the design efficacy of the Indigenous titanium Dental implant "INDIDENT" and stated that the stress concentration and distribution was affected by the diameter of the implant and not by the length variation of Implants.

**Balik A et al (2012)**[31] investigated the strain distributions in the connection areas of different implant-abutment connection systems under similar loading conditions and stated that the implant-abutment connection system with external hexagonal connection showed the highest strain values, and the internal hexagonal implant-abutment connection system showed the lowest strain values.

**Premnath K et al (2013)**[32] evaluated the pattern of stress distribution with two different implant designs in four different densities of bone and reported that stresses observed were more for the threaded implants in all the four densities of bone when compared to that of the cylindrical implants and concluded that the cylindrical implant design was more favorable in softer bone than the threaded implant design**.**

**Mijiritsky E et al (2013)**[33] evaluated the influence of implant length and diameter on implant survival rates and reported that implant length and diameter were not significant factors affecting implant survival during the first 2 years of function and also concluded that short (<10 mm) implants and narrow (<3.75 mm) implants can be placed successfully in the partially edentulous patients.

**Fawzi S (2013)**[34] evaluated the effect of implant design on stress distribution and micro displacement of an immediately loaded implant for full arch screw retained cantilevered prosthesis and concluded that increasing implant diameter leads to decreased bone induced stresses and decreased implant micro displacement leading to better initial stability.

**Cavalli N et al (2014)**[35] compared bone stress transmitted by single short implant and single standard length implant with different prosthetic crown configurations and concluded that crown height and implant length seem to be the influencing factor in the peri-implant bone stress.

**Moriwaki H et al (2014)**[36] compared the stress distribution on peri-implant bone by a short implant with bi-cortical anchorage and a 13 mm length implant with sinus augmentation quantitatively and suggested that the short implant with bi-cortical anchorage may be clinically more useful than the normal length implant with sinus augmentation.

**Ji-Man P et al (2014)**[37] evaluated the clinical criteria for placement of the implant crown and suggested that for the patient with atrophied alveolar ridge following the loss of molar teeth, von-Mises stress on implant components was the lowest under the 30° oblique load at the 5 mm offset point.

**Bhat V et al (2014)**[38] compared and evaluated the influence of different lengths of implants on stress upon bone in mandibular posterior and concluded that under static horizontal loading conditions, shorter implants transfer more stresses to the surrounding bone and under static vertical loading they transmit lesser load to the surrounding bone.

**Arsalanloo Z et al (2014)**[39] compared optimum length and diameter of 26 different commercial dental implants by considering the variability in diameter and length and material of implants for missing upper/lower lateral incisor and concluded that implants with larger diameters are more stable and others with smaller diameters can have better performance when increasing their length.

**Gehrke S et al (2014)**[40] compared the stress dissipation in bone surrounding a standard and a short length implant under simulated loading and stated that implant length did not affect the amount of total stress distributed to implant-surrounding bone.

**Shetty S et al (2014)**[41] reviewed the insufficient alveolar bone height for implant placement as a commonly seen problem in the posterior jaws and proposed that short dental implants have been successfully used in such situations with comparable survival rates with that of longer implants.

**Balkaya M C (2014)**[42] analyzed the biomechanical behavior of implants with varying number, inclination, and size and concluded that increasing diameter of implants decreased high stress concentration in the cortical bone.

**Anand S et al (2014)**[43] evaluated the stress distribution pattern at the implant bone and implant abutment interface with varying implant length and concluded that stresses at the peri-implant bone as well as at the implant abutment junction decreased on both the sides as the implant length increased.

**Saad A M et al (2014)**[44] evaluated the effect of changing implant dimensions on the stress distribution in the supporting structures in implant-supported partial over-dentures and stated that the increase in the implant diameter significantly reduced the stresses transmitted to the supporting bone compared to increasing the implant length.

**Reddy KR et al (2014)**[45] evaluated ideal stress distribution in cancellous and cortical bone under axial and non-axial loading using different implant dimensions and designs and concluded that, for implants with a wider diameter and in threaded implant with a shorter length, there was favorable distribution of stress and strain pattern during axial and non-axial loading.

**Mahajan S et al (2015)**[46] conducted a study to find out the best thread shape by comparing stress induced in cortical and cancellous bone and concluded that stresses induced in bone of tapered cylindrical implant with alternate thread shape of triangular and square is less as compared to tapered cylindrical implant with alternate thread shape of triangular and trapezoidal.

**Gehrke S A (2016)**[47] compared the influence of implant design in the load transfer on bone under simulated occlusal loading, using photo-elastic analysis and found that lower stress was observed at the crestal bone in short conical implant and standard conical implant compared to standard long cylindrical implant and standard short cylindrical implants.

**Goiato M C et al (2016)**[48] conducted a study to assess the effect of different short implant design on stress distribution through photo elastic analysis and concluded that the macro-design influenced the amount of stress distributed to the bone when short dental implants are placed.

**Sivamurthy G et al (2016)**[49] evaluated the stress patterns produced in mini-implant and alveolar bone, for various implant dimensions, under different directions of simulated orthodontic force, using a three-dimensional finite element method and concluded that all mini-implants should be inserted at a 30° angle into the bone for reduced stress and improved stability.

**Abraham HM et al (2016)**[50] conducted a study to evaluate the effect of implant and abutment diameter on stress distribution in the peri-implant area and found out that the von Mises compressive, and tensile stresses in the peri-implant bone were lower in the regular platform model compared to the narrow platform model.

# MATERIALS AND METHODOLOGY

Finite element modeling is described as the representation of the geometric model in terms of a finite number of elements and nodes which are building blocks of the numerical representation of the model. An element which may consist of triangular or quadrilateral shapes is mathematical matrix of the collective interaction among degrees of freedom whose (displacements) and actions (forces) of structure under load are considered to exist. In addition to information about element and nodes, this model also contains information about material and other properties, loading and boundary conditions.

Here modeling software **'SOLIDWORKS-2014'** was used which is a solid modeling computer aided design (CAD) and computer aided engineering (CAE) computer program. Once a structure is numerically created and material properties are assigned it can be analyzed for stress distributions during force application using finite element software. The finite element software used in this study was **'ANSYS Workbench'**. The stresses were expressed as compressive (which are negative) or tensile (which are positive). The global (x, y, z directional axes) combination of the absolute values squared of all stresses-is known as Von Mises stresses.

Finite element analysis is a numerical method based on the principle of dividing a structure into finite number of small elements that are inter connected with each other at the corner points or nodes having three degrees of freedom which translates in X, Y & Z directions. Each element is assigned unique elastic properties (Poisson's ratio and modulus of elasticity) to represent the materials modelled and for each elements, its mechanical behavior can be written as a function of displacement of the nodes. These nodes are submitted to certain loading conditions, resulting in behavior of the model similar to the structures it represents. When a computer analysis is performed, a system of simultaneous equations can be solved to relate all forces and displacements at the nodes. From this stresses and stress contours can be established in each element and thus for the whole body. The method has gained increased usage in biomechanical disciplines including orthopedic, cardiac and dental mechanics.

## System configuration

A computer with the following system configuration was used

- Windows edition- Windows 7 Ultimate, service pack 2
- Processor- Intel® Core ™ i5 CPU M 430@ 2.27GHz 2.26GHz
- RAM: 4.00GB
- 64-Bit operating system

The geometric model of mandibular body was constructed based on the measurements of a dried human edentulous mandible and four different implant designs were designed which were to be placed in the body of mandible at planned specific sites.

## Geometric model of Mandible

The edentulous section of the mandible was modelled based on the measurements of a dried human edentulous mandible.

- The dimensions of mandibular section are -
  - ✓ Height - 15mm
  - ✓ Width - 9mm

- Thickness of cortical bone
  - ✓ Crestal - 2mm
  - ✓ Buccal and lingual - 2mm

## Implant

Four different implant designs were designed according to the following dimensions:-

- Cylindrical implant
  - ✓ Length of the implant : 11 mm
  - ✓ Diameter of the implant : 3.8 mm
- Tapered implant (having uniform 5° taper)
  - ✓ Length of the implant : 11mm
  - ✓ Diameter of the implant : 3.8mm

- Hybrid implant
  - ✓ Length of the implant : 11 mm
  - ✓ Diameter of the implant : 3.8 mm
- Short implant
  - ✓ Length of the implant : 6mm
  - ✓ Diameter of the implant : 6mm

## Material properties

Material property values are assigned to the different materials included in the model based on previously published data[52-58].The properties corresponding to various materials used in the analysis are given in table I

**TABLE NO-1-MECHANICAL PROPERTIES OF MATERIALS**

| MATERIALS | | YOUNG' MODULUS (MPa) | POISSONS RATIO |
|---|---|---|---|
| 1 | TITANIUM-IMPLANT | 110000 | 0.35 |
| 2 | CANCELLOUS BONE | 1370 | 0.30 |
| 3 | CORTICAL BONE | 13700 | 0.30 |

The program used implied several assumptions with regard to the mechanical properties of the simulated structures.

**1. Homogeneity**

The mechanical properties of a material are thought to be the same in the entire structure.

**2. Isotropy**

The material properties are same in all directions

**3. Linear elasticity**

The deformation or strain of the structure is proportional to the applied force and independent of the strain rate.

## BONE IMPLANT INTERFACE

A continuous bond between bone and implant along the entire interface were assumed, which under loading resulted in no relative motion between the bone and implant. This was accepted to be the clinical situation assuming the implant were completely osseointegrated.

## Loads applied

Two clinical situations were considered for load application:

- Axial loads of magnitudes **250N, 300N, 400N** and **700N** are applied as during uniform bilateral biting which are directed downwards parallel to long axis of the implant.

- Non-Axial loads of magnitudes **100N, 200N, 300N** and **400N** are given at an angle of 15°from the long axis of the implant as during lateral movements.

## Analysis

A total of 4 models were formed and grouped into two for ease of analysis.

- **Group 1** consisted of 4 models on which axial loads were applied
- **Group II** consisted of 4 models on which non-axial loads were applied.

**Model 1** consisted of mandibular section with short implant placed in the molar region.

**Model 2** consisted of mandibular section with tapered implant placed in the molar region.

**Model 3** consisted of mandibular section with cylindrical implant placed in the molar region.

**Model 4** consisted of mandibular section with hybrid implant placed in the molar region.

The different models as discussed above were analysed using the linear static module of the finite element software to obtain the deformation pattern and the stress distribution in the structure.

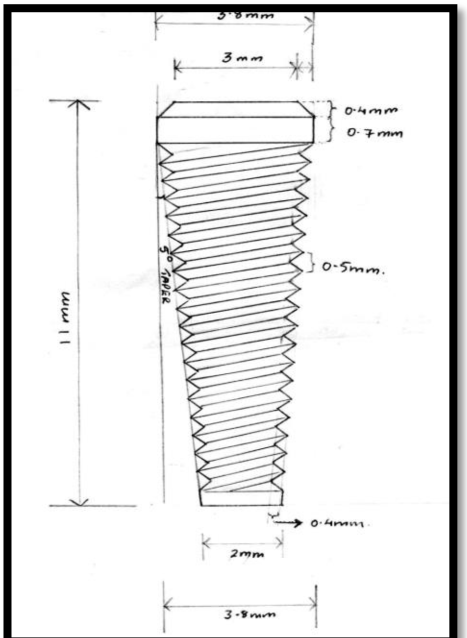
The output form, the finite element analysis of a 3D model of this mesh size, will be very voluminous. Hence in order to better visualize the stress state in the structure, using colour graphics the calculated stresses are presented in the form of colour bands. Each colour band represents a particular range of stress values.

## STRESSES

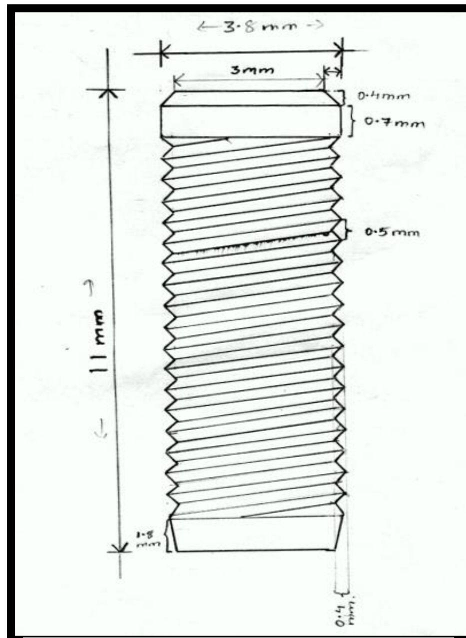
The stress distribution in the structure is presented in the form of contour plots for different cases of the model studied. In order to get a clear picture of the stress status the contour plots have been made separately for areas of special interest i.e. implant and bone around implant. For comparison of the magnitude of stress in each model, the peak Von Mises stresses in the areas of special concern was tabulated.

# *FIGURES*

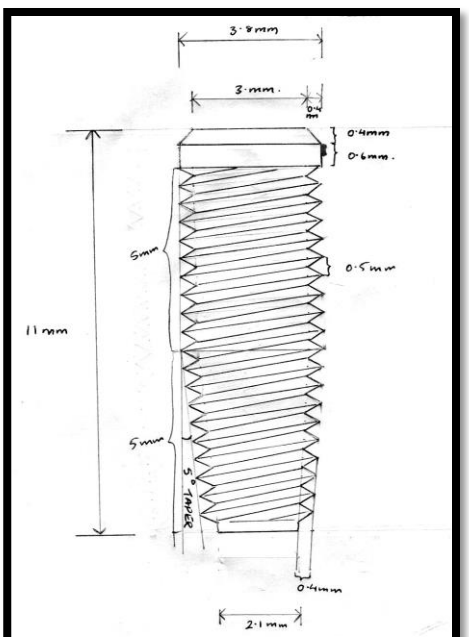
# FIGURE: 1-IMPLANT DESIGN SKETCHES



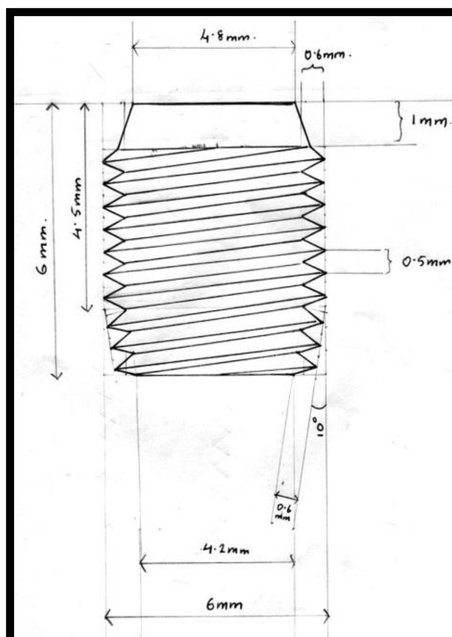

**TAPERED IMPLANT**




**CYLINDRICAL IMPLANT**

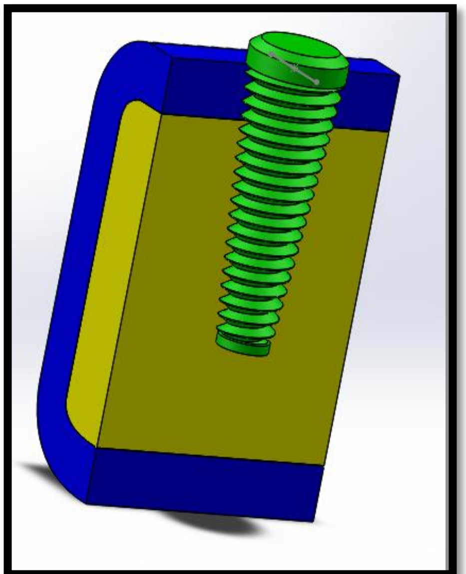



**HYBRID IMPLANT**

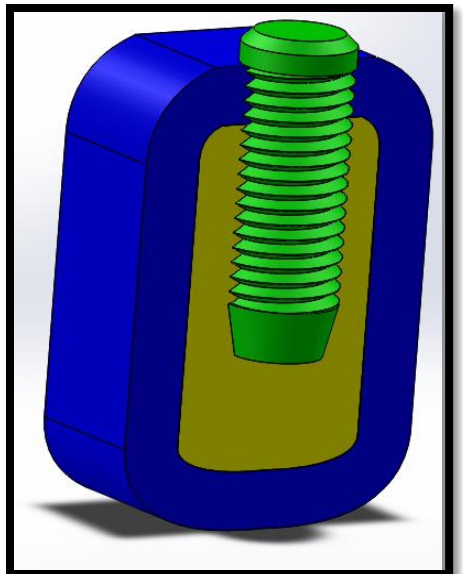



**SHORT IMPLANT**

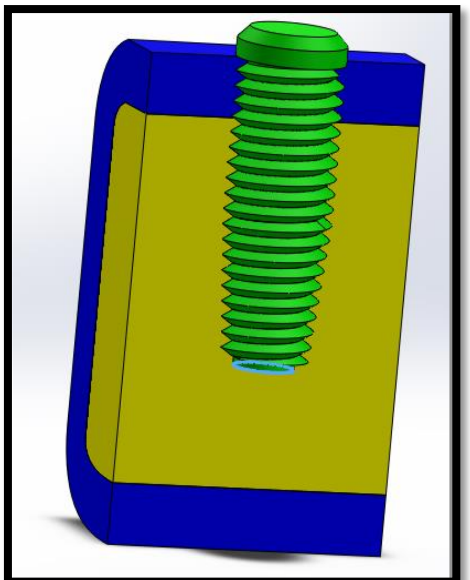
# FIGURE: 2-COMPLETED IMPLANT MODELS



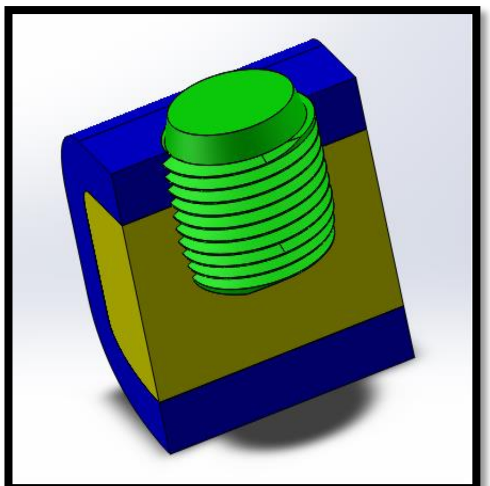
**TAPERED IMPLANT**



**CYLINDRICAL IMPLANT**

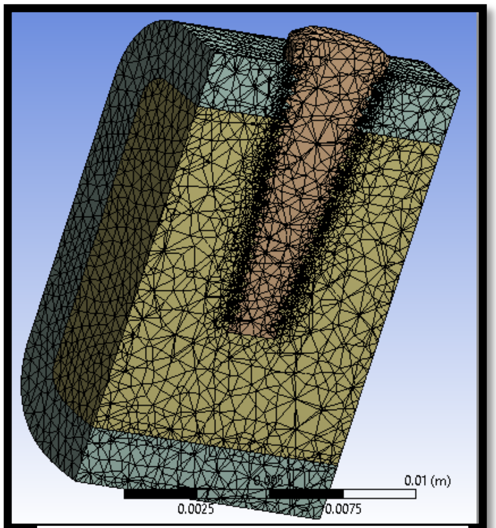


**HYBRID IMPLANT**

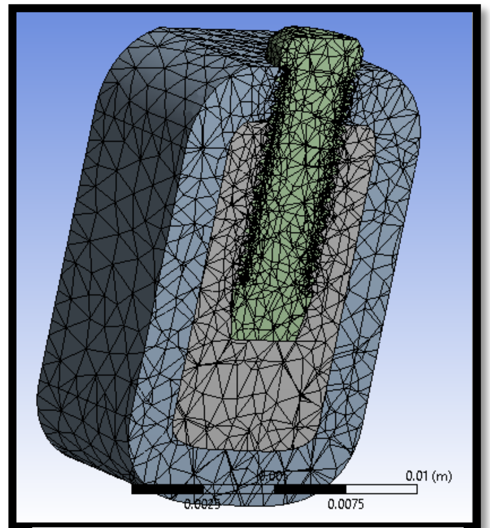


**SHORT IMPLANT**

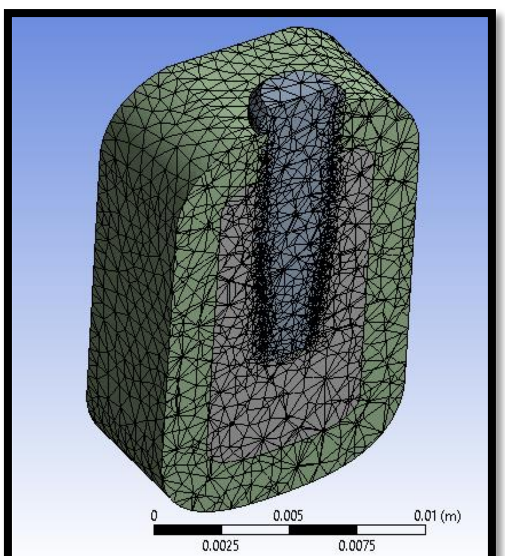
# FIGURE: 3- MESHED IMPLANT MODELS



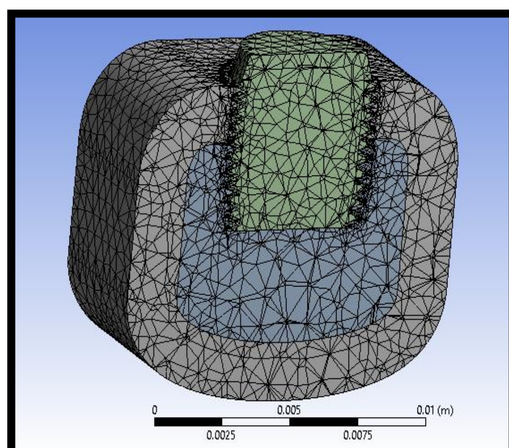

**TAPERED IMPLANT**




**CYLINDRICAL IMPLANT**




**HYBRID IMPLANT**




**SHORT IMPLANT**

## Finite Element Analysis

### Normally Applied Load on Tapered Implant

Load = 250N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 4(a) Equivalent Von Mises

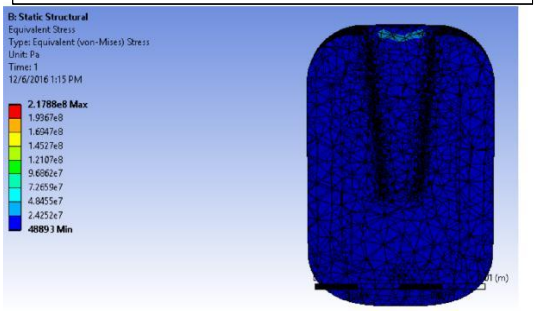



Figure 4(b) Maximum Principal Stress

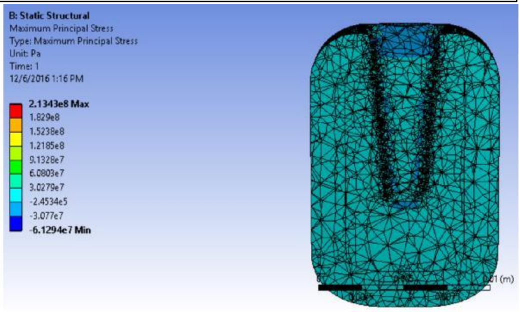
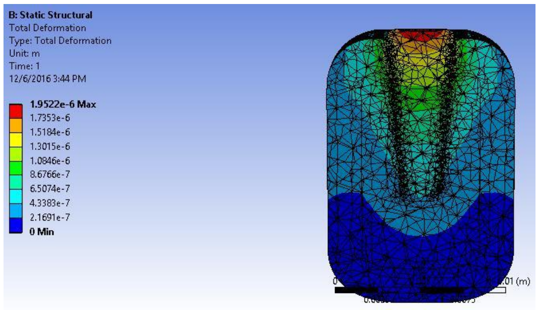



Figure 4(c) Total deflection




Load = 300N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:5 (a) Equivalent Von Mises Stress

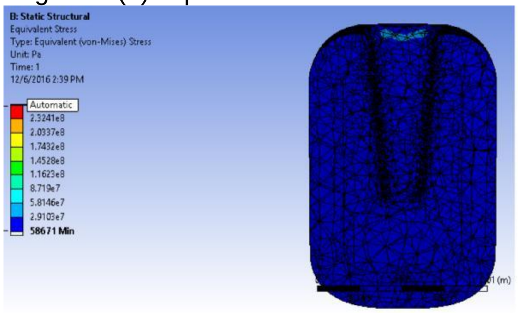



Figure:5 (b) Maximum Principal Stress

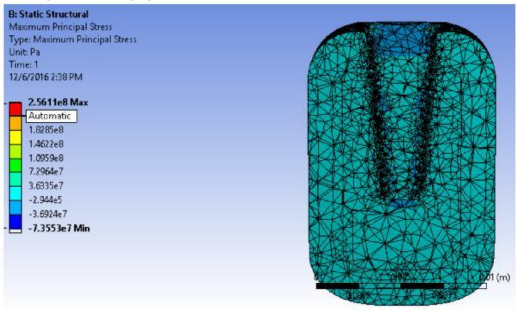
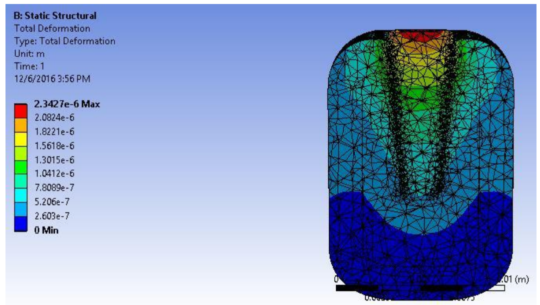


Figure: 5 (c) Total Deformations




Load = 400N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:6 (a) Equivalent Von Mises Stress

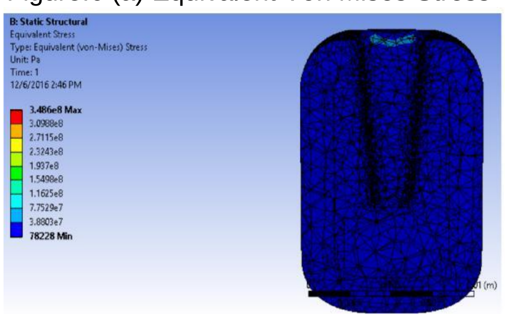



Figure:6 (b) Maximum Principal Stress

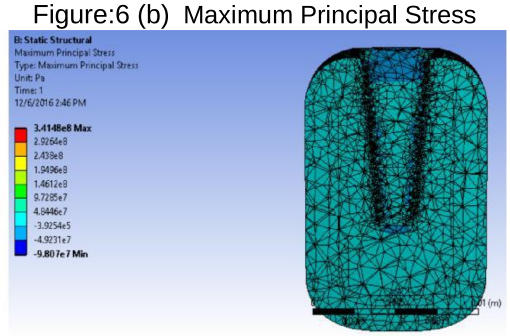
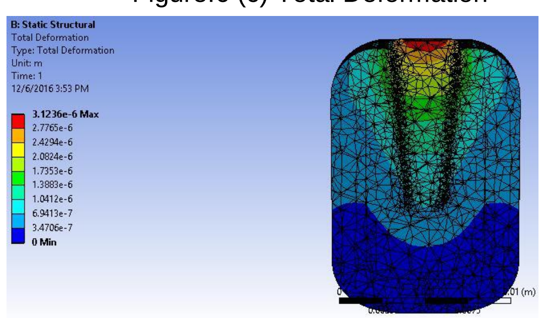



Figure:6 (c) Total Deformation



Load = 700N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:7 (a)Equivalent Von Mises Stress

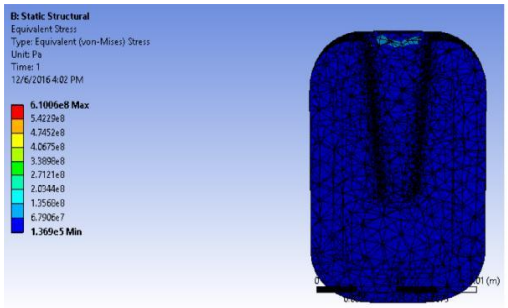



Figure:7 (b) Maximum Principal Stress

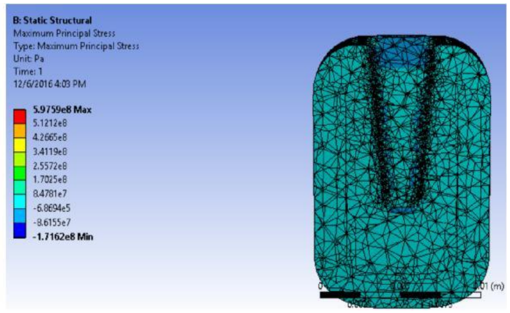
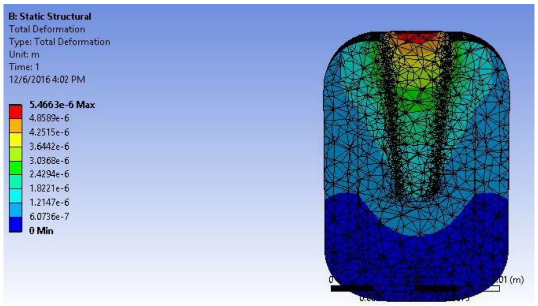



Figure:7 (c) Total Deformation




## Normally Applied Load on Cylindrical Implant

Load = 250N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:8 (a)Equivalent Von Mises Stress

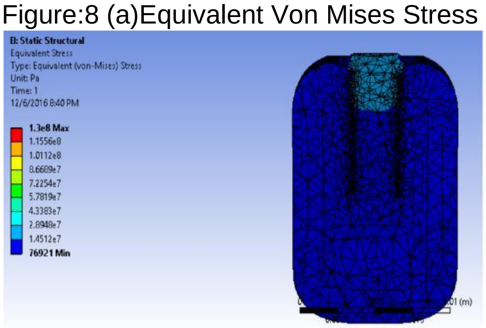



Figure:8 (b) Maximum Principal Stress

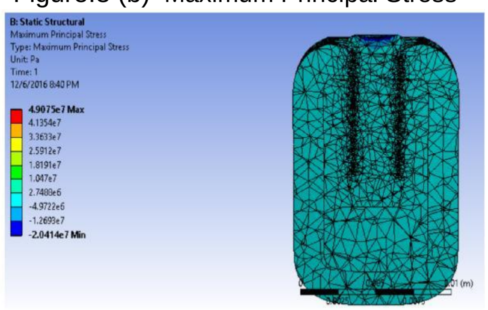
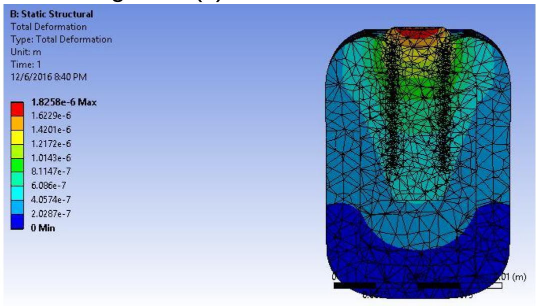


Figure:8 (c)Total Deformation




Load = 300N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure: 9 (a) Equivalent Von Mises Stress

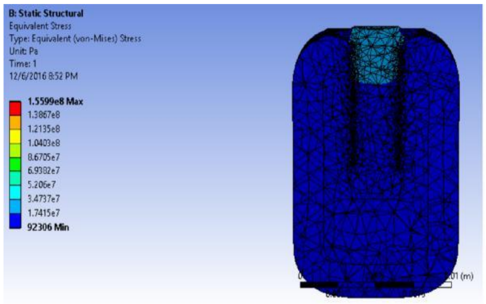
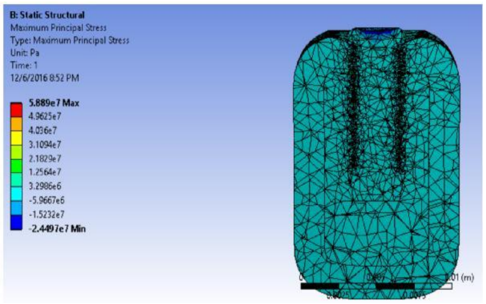



Figure:9 (b) Maximum Principal Stress




Load = 400N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:10 (a)Equivalent Von Mises Stress

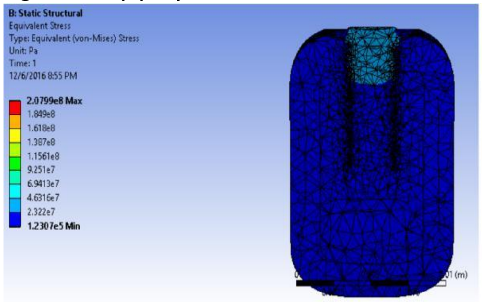



Figure:10 (b) Maximum Principal Stress

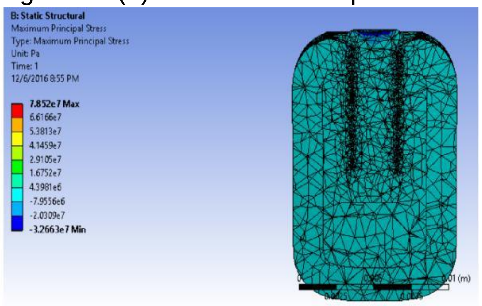
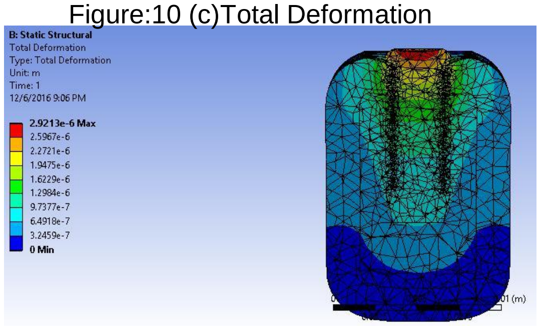


Figure:10 (c)Total Deformation




Load = 700N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure:11 (a) Equivalent Von Mises Stress

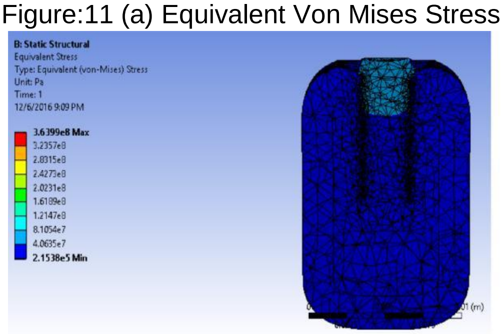



Figure:11 (b) Maximum Principal Stress

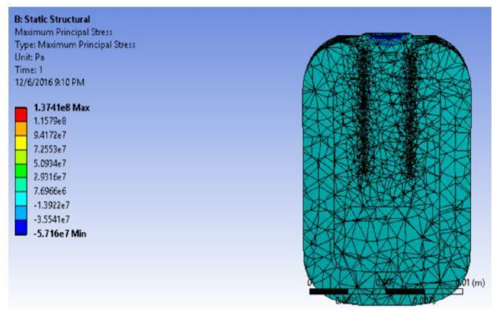
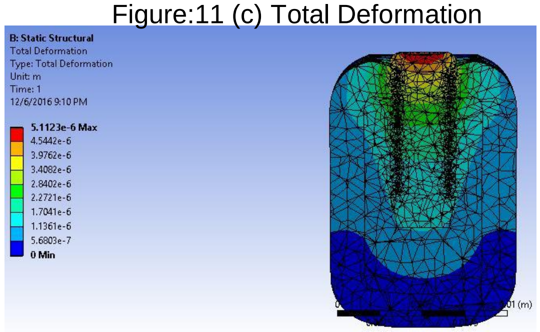



Figure:11 (c) Total Deformation



## Normally Applied Load on Hybrid Implant

Load = 250N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 12(a) Equivalent Von Mises Stress

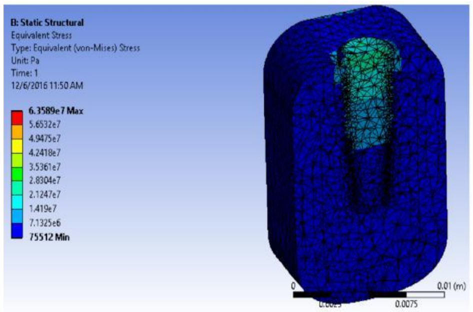



Figure 12(b) Maximum Principal Stress

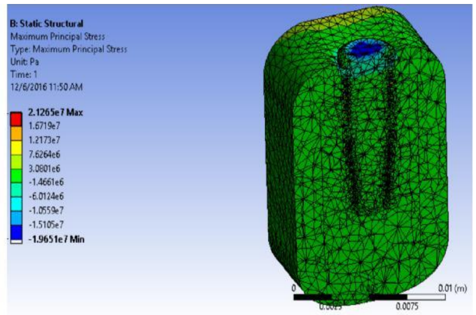
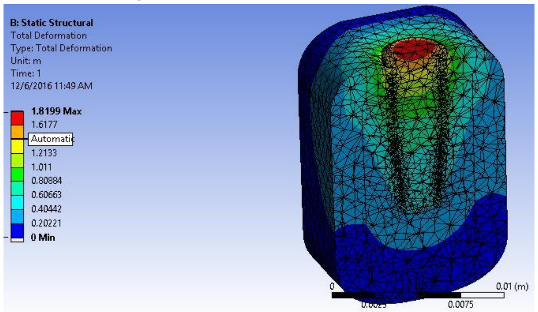



Figure 12(c) Total Deformation




Load = 300N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 13(a) Equivalent Von Mises Stress

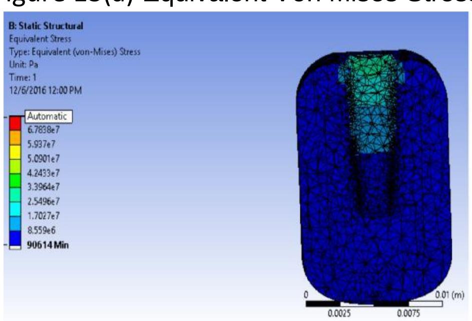



Figure 13(b) Maximum Principal Stress

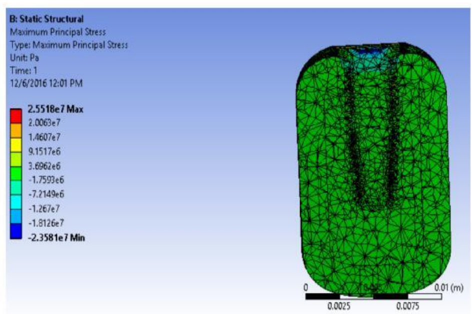
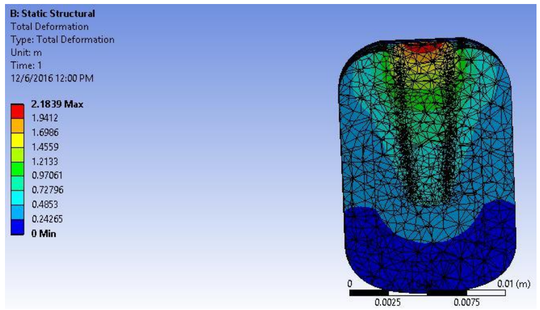


Figure 13(c) Total Deformation




Load = 400N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 14(a) Equivalent Von Mises Stress

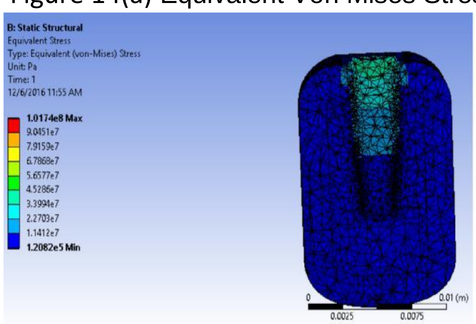



Figure 14(b) Maximum Principal Stress

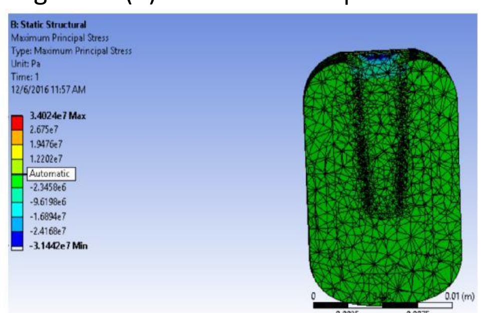
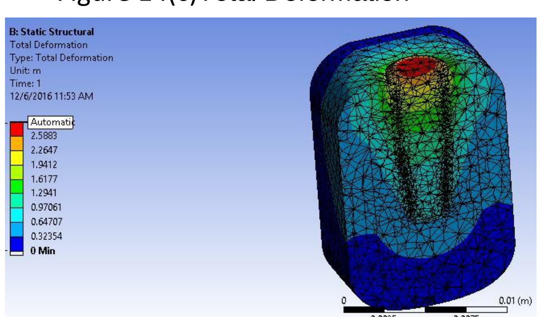



Figure 14(c)Total Deformation



Load = 700N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 15(a) Equivalent Von Mises Stress

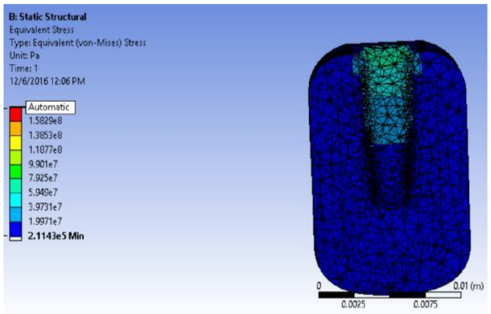



Figure 15(b) Maximum Principal Stress

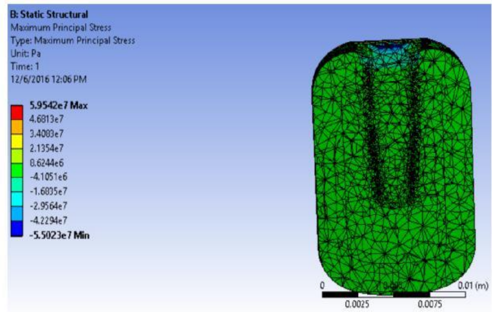
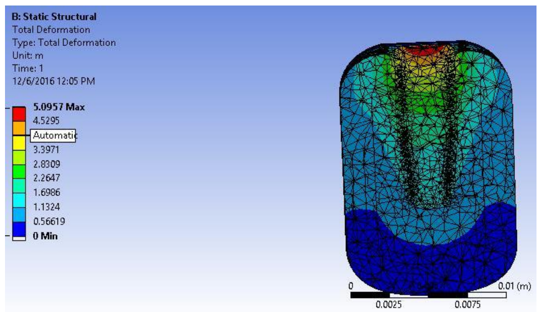



Figure 15(c) Total Deformation




## Normally Applied Load on Short Implant

Load = 250N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 16(a) Equivalent Von Mises Stress

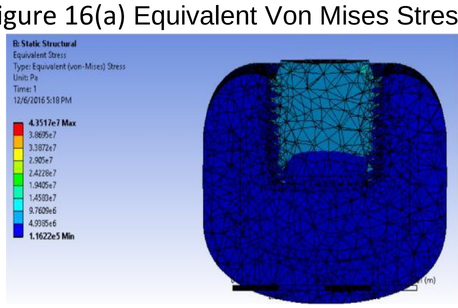



Figure 16(b) Maximum Principal Stress

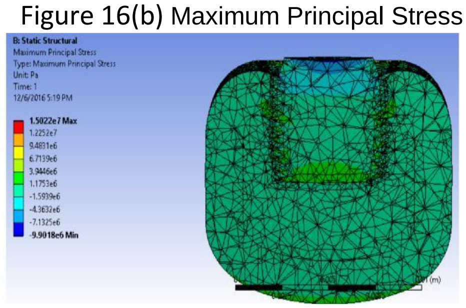
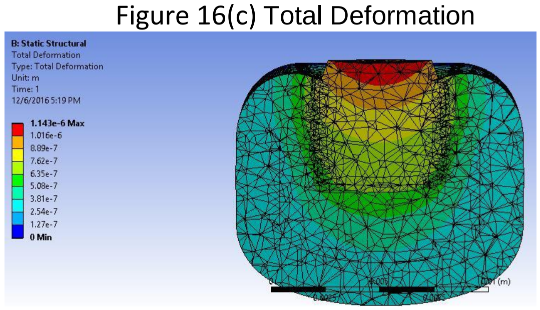



Figure 16(c) Total Deformation



Load = 300N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 17(a) Equivalent Von Mises Stress

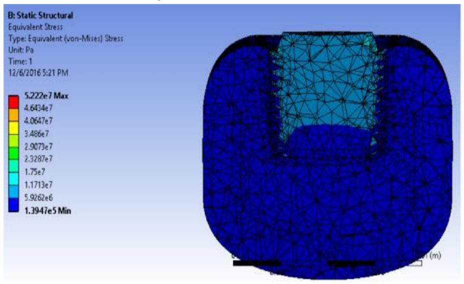



Figure 17(b) Maximum Principal Stress

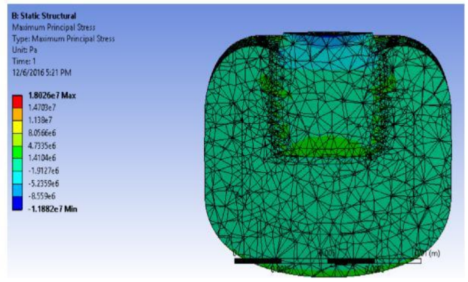
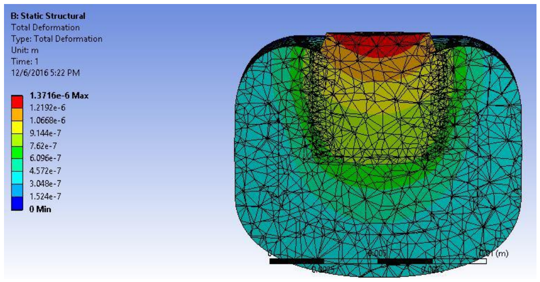



Figure 17(c) Total Deformation




Load = 400N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 18(a) Equivalent Von Mises Stress

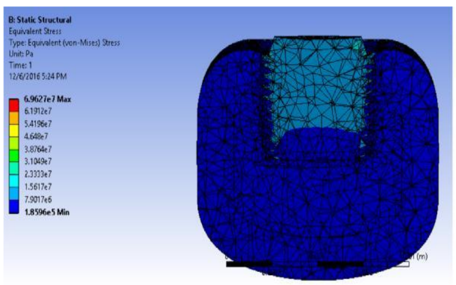



Figure 18(b) Maximum Principal Stress

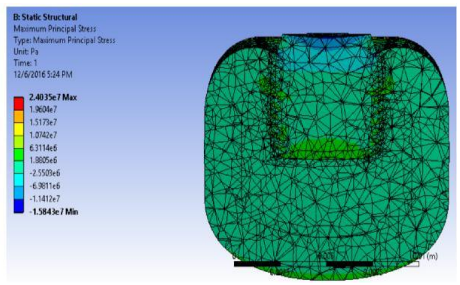
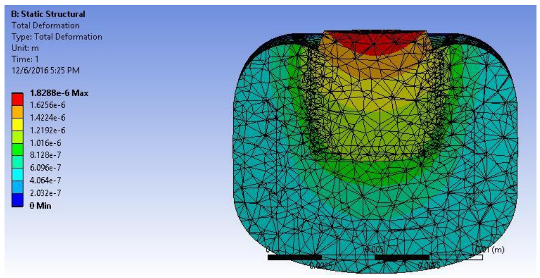



Figure 18(c) Total Deformation



Load = 700N

The sectional plots of Equivalent Stress (Von Mises), the Maximum Principal Stress and Total Deformation are as follows.

Figure 19(a) Equivalent Von Mises Stress

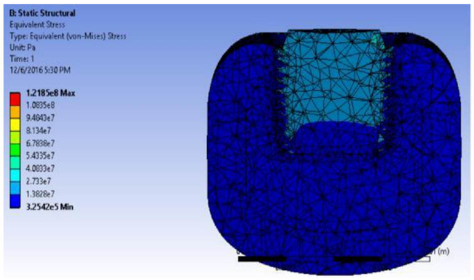



Figure 19(b) Maximum Principal Stress

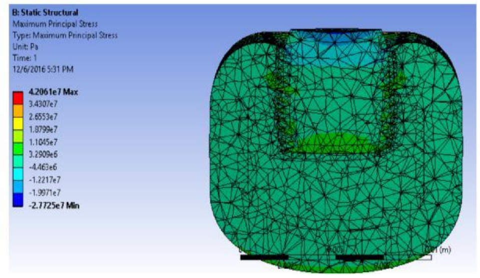
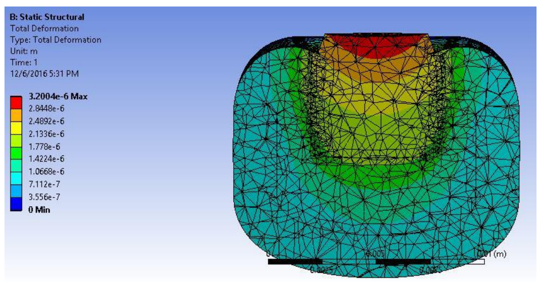



Figure 19(c) Total Deformation



# *RESULTS AND OBSERVATIONS*

The present study evaluated the stress distribution of eight finite element models which were grouped into two, Group I consisted of models on which axial loads of magnitudes 250N, 300N, 400N and 700N were applied and group II consisted of models on which non-axial loads of magnitudes 100N, 200N, 300N and 400N were applied.(Table.no-2)

For all the models peak Von Mises stresses and Principal stresses were studied.

**TABLE NO-2- Description of groups**

| GROUPS | MODELS |
|---|---|
| **GROUP I AXIAL LOADING (250N,300N,400N &700N)** | **1. SHORT IMPLANT DESIGN** |
| | **2. HYBRID IMPLANT DESIGN** |
| | **3. CYLINDRICAL IMPLANT DESIGN** |
| | **4. TAPEREDIMPLANT DESIGN** |
| **GROUP II NON-AXIAL LOADING (100N,200N,300N & 400N)** | **1. SHORT IMPLANT DESIGN** |
| | **2. HYBRID IMPLANT DESIGN** |
| | **3. CYLINDRICAL IMPLANT DESIGN** |
| | **4. TAPEREDIMPLANT DESIGN** |

## RESULTS

### Table No-3 Shows values of maximum Von Mises equivalent stresses in group I:

When an axial load of **250N** was applied onto the implant models the maximum Von Mises value obtained for short implant was **43.5 MPa,** hybrid implant was **63.6 MPa**, cylindrical implant was **130 MPa** and for tapered was **218 MPa**.

On a load of 300N the maximum Von Mises value obtained for short implant was **52.2 MPa**, hybrid implant was **76.3 MPa,** cylindrical implant was **156 MPa** and for tapered implant was **261 MPa.**

On a load of **400N** the maximum Von Mises value obtained for short implant was **69.6 MPa,** hybrid implant was **102 MPa**, cylindrical implant was **208 MPa** and for tapered implant was **349 MPa**.

On a load of **700N** the maximum Von Mises value obtained for short implant was **122 MPa**, hybrid implant was **178 MPa**, cylindrical implant was **364 MPa** and for tapered implant was **610 MPa.**

| TABLE NO-3:VON MISES STRESSES PRODUCED IN GROUP I | | | |
|---|---|---|---|
| **MODEL** | **LOAD(N)** | **EQUIVALENT MAX: VON MISES STRESS** | |
| | | **Pa** | **MPa** |
| **SHORT IMPLANT** | **250** | **4.35E+07** | **43.5** |
| | **300** | **5.22E+07** | **52.2** |
| | **400** | **6.96E+07** | **69.6** |
| | **700** | **1.22E+08** | **122** |
| | | | |
| **HYBRID IMPLANT** | **250** | **6.36E+07** | **63.6** |
| | **300** | **7.63E+07** | **76.3** |
| | **400** | **1.02E+08** | **102** |
| | **700** | **1.78E+08** | **178** |
| | | | |
| **CYLINDRICAL IMPLANT** | **250** | **1.30E+08** | **130** |
| | **300** | **1.56E+08** | **156** |
| | **400** | **2.08E+08** | **208** |
| | **700** | **3.64E+08** | **364** |
| | | | |
| **TAPERED IMPLANT** | **250** | **2.18E+08** | **218** |
| | **300** | **2.61E+08** | **261** |
| | **400** | **3.49E+08** | **349** |
| | **700** | **6.10E+08** | **610** |

**Table No-4 Shows maximum Von Mises equivalent stresses in group II:**

When non-axial load of **100N** was applied at an angle of 15° the maximum Von Mises value obtained for short implant was **23.9 MPa**, hybrid implant was **36.8 MPa,** cylindrical implant was **93.8 MPa** and for tapered implant was **97.8 MPa.**

On a non-axial load of **200N** the maximum Von Mises value obtained for short implant was **47.8 MPa**, hybrid implant was **73.6 MPa**, cylindrical implant was **188 MPa** and for tapered implant was **196 MPa.**

On a non-axial load of **300N** the maximum Von Mises value obtained for short implant was **71.7 MPa**, hybrid implant was **110 MPa**, cylindrical implant was **281 MPa** and for tapered was **293 MPa.**

On a non-axial load of **400N** the maximum Von Mises value obtained for short implant was **95.6 MPa**, hybrid implant was **147 MPa**, cylindrical implant was **375 MPa** and for tapered was **391 MPa**.

| TABLE NO-4: VON MISES STRESSES PRODUCED IN GROUP II | | | |
|---|---|---|---|
| **MODEL** | **LOAD(N)** | **EQUIVALENT MAX: VON MISES STRESS** | |
| | | **Pa** | **MPa** |
| **SHORT IMPLANT** | **100** | **2.39E+07** | **23.9** |
| | **200** | **4.78E+07** | **47.8** |
| | **300** | **7.17E+07** | **71.7** |
| | **400** | **9.56E+07** | **95.6** |
| | | | |
| **HYBRID IMPLANT** | **100** | **3.68E+07** | **36.8** |
| | **200** | **7.36E+07** | **73.6** |
| | **300** | **1.10E+08** | **110** |
| | **400** | **1.47E+08** | **147** |
| | | | |
| **CYLINDRICAL IMPLANT** | **100** | **9.38E+07** | **93.8** |
| | **200** | **1.88E+08** | **188** |
| | **300** | **2.81E+08** | **281** |
| | **400** | **3.75E+08** | **375** |
| | | | |
| **TAPERED IMPLANT** | **100** | **9.78E+07** | **97.8** |
| | **200** | **1.96E+08** | **196** |
| | **300** | **2.93E+08** | **293** |
| | **400** | **3.91E+08** | **391** |

**Table No-5 Shows maximum Principal stresses in group I :**

When an axial load of **250N** was applied onto the implant models the maximum principal stress value obtained for short implant was **15 MPa**, hybrid implant was **21.3 MPa**, cylindrical implant was **49.1 MPa** and for tapered implant was **213MPa**.

On a load of **300N** the maximum principal stress value obtained for short implant was **18 MPa**, hybrid implant was **25.5 MPa**, cylindrical implant was **58.9 MPa** and for tapered implant was **256 MPa**.

On a load of **400N** the maximum principal stress value obtained for short implant was **24 MPa**, hybrid implant was **34 MPa**, cylindrical implant was **78.5 MPa** and for tapered implant was **341 MPa**.

On a load of **700N** the maximum principal stress value obtained for short implant was **42.1 MPa**, hybrid implant was **59.5 MPa**, cylindrical implant was **137 MPa** and for tapered implant was **598 MPa**.

| TABLE NO-5: MAXIMUM PRINCIPAL STRESS PRODUCED IN GROUP I | | | |
|---|---|---|---|
| MODEL | LOAD(N) | MAXIMUM PRINCIPAL STRESS | |
| | | Pa | MPa |
| SHORT IMPLANT | 250 | 1.50E+07 | 15 |
| | 300 | 1.80E+07 | 18 |
| | 400 | 2.40E+07 | 24 |
| | 700 | 4.21E+07 | 42.1 |
| | | | |
| HYBRID IMPLANT | 250 | 2.13E+07 | 21.3 |
| | 300 | 2.55E+07 | 25.5 |
| | 400 | 3.40E+07 | 34 |
| | 700 | 5.95E+07 | 59.5 |
| | | | |
| CYLINDRICAL IMPLANT | 250 | 4.91E+07 | 49.1 |
| | 300 | 5.89E+07 | 58.9 |
| | 400 | 7.85E+07 | 78.5 |
| | 700 | 1.37E+08 | 137 |
| | | | |
| TAPERED IMPLANT | 250 | 2.13E+08 | 213 |
| | 300 | 2.56E+08 | 256 |
| | 400 | 3.41E+08 | 341 |
| | 700 | 5.98E+08 | 598 |

**Table No-6 Shows maximum principal stresses in Group II:**

When non-axial load of **100N** was applied at an angle of 15° the maximum principal stress value obtained for short implant was **6.02 MPa**, hybrid implant was **5.35 MPa**, cylindrical implant was **36.6 MPa** and for tapered implant was **70.6 MPa**.

On a non-axial load of **200N** the maximum principal stress value obtained for short implant was **12 MPa**, hybrid implant was **10.7 MPa**, cylindrical implant was **73.3 MPa** and for tapered implant was **141 MPa.**

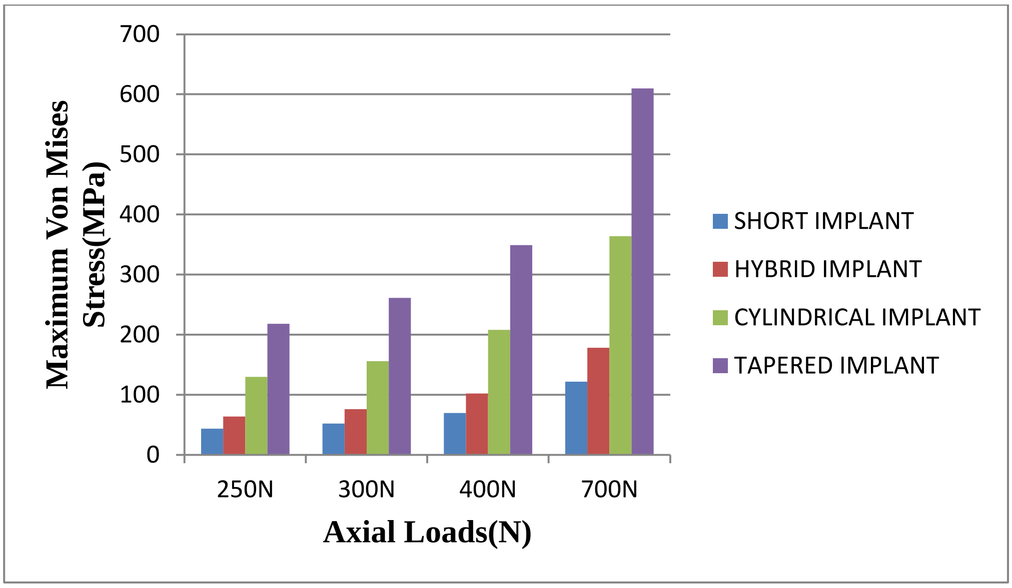
On a non-axial load of **300N** the maximum principal stress value obtained for short implant was **18.1 MPa**, hybrid implant was **16.1 MPa**, cylindrical implant was **110 MPa** and for tapered implant was **212 MPa**.

On a non-axial load of **400N** the maximum principal stress value obtained for short implant was **24.1 MPa**, hybrid implant was **21.4 MPa**, cylindrical implant was **147 MPa** and for tapered implant was **283 MPa.**

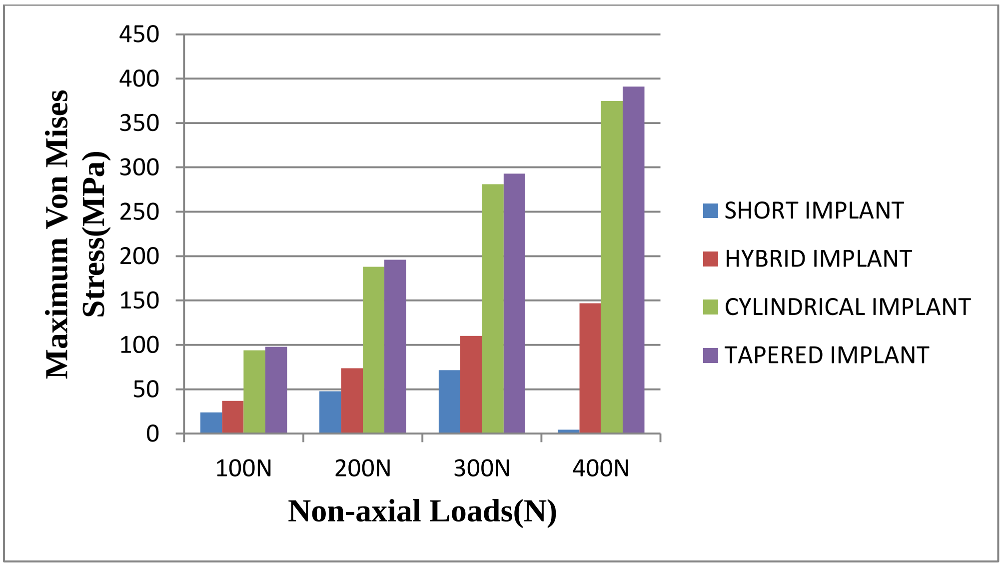
| TABLE NO-6: MAXIMUM PRINCIPAL STRESS PRODUCED GROUP II | | | |
|---|---|---|---|
| MODEL | LOAD(N) | MAXIMUM PRINCIPAL STRESS | |
| | | Pa | MPa |
| SHORT IMPLANT | 100 | 6.02E+06 | 6.02 |
| | 200 | 1.20E+07 | 12 |
| | 300 | 1.81E+07 | 18.1 |
| | 400 | 2.41E+07 | 24.1 |
| | | | |
| HYBRID IMPLANT | 100 | 5.35E+06 | 5.35 |
| | 200 | 1.07E+07 | 10.7 |
| | 300 | 1.61E+07 | 16.1 |
| | 400 | 2.14E+07 | 21.4 |
| | | | |
| CYLINDRICAL IMPLANT | 100 | 3.66E+07 | 36.6 |
| | 200 | 7.33E+07 | 73.3 |
| | 300 | 1.10E+08 | 110 |
| | 400 | 1.47E+08 | 147 |
| | | | |
| TAPERED IMPLANT | 100 | 7.06E+07 | 70.6 |
| | 200 | 1.41E+08 | 141 |
| | 300 | 2.12E+08 | 212 |
| | 400 | 2.83E+08 | 283 |

# *GRAPHS*

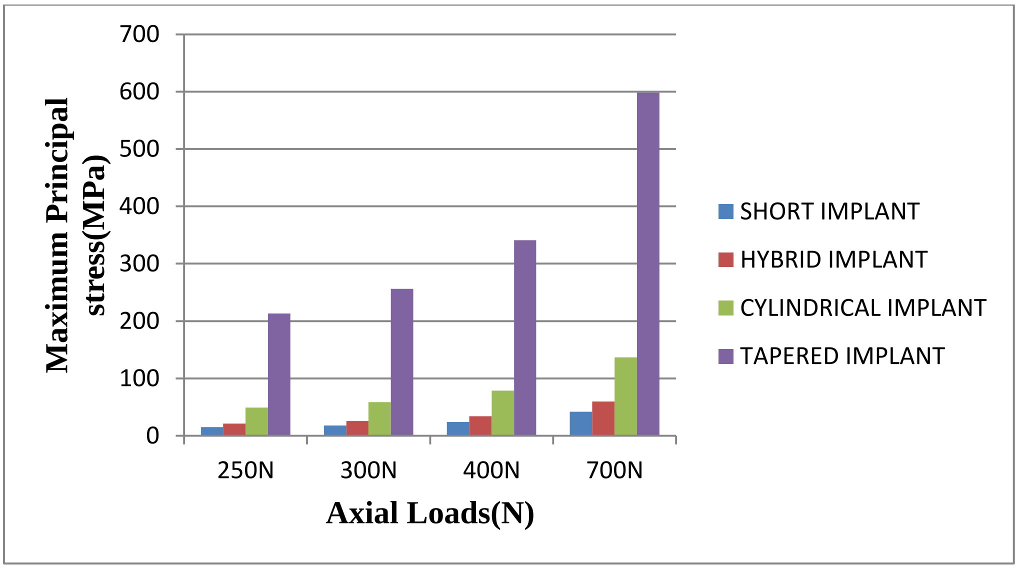
Graph No: 9-Graph depicting the multiple comparison of Von Mises stresses in Group I



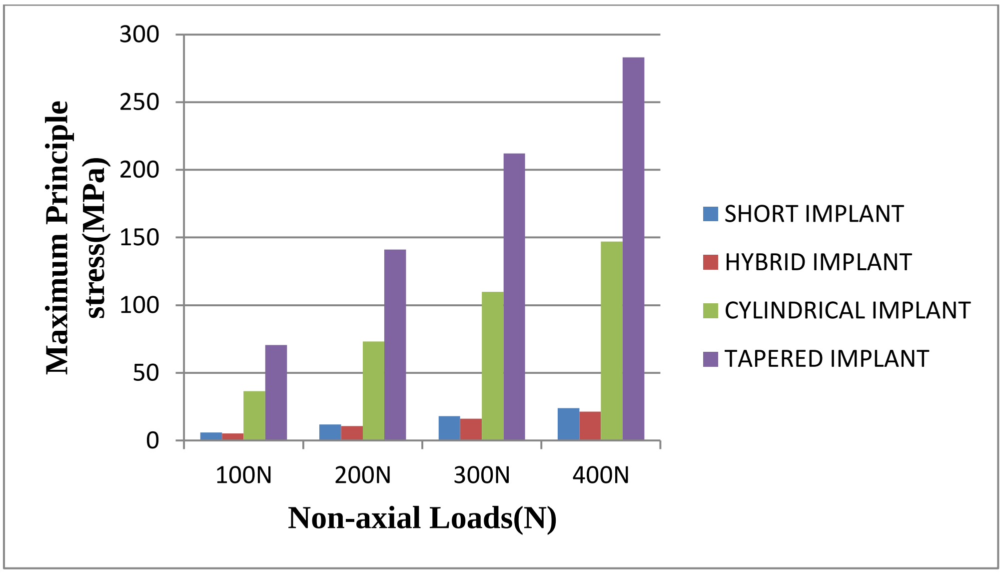

Graph No: 10-Graph depicting the multiple comparison of Von Mises stresses in Group II



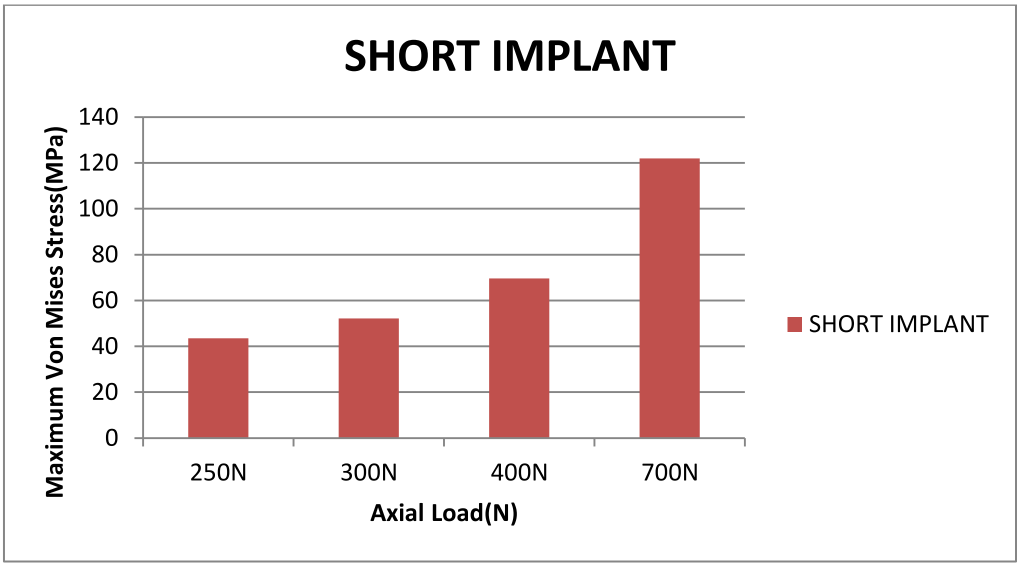
**Graph No: 11-Graph depicting the multiple comparison of Max: Principal stresses in Group I**



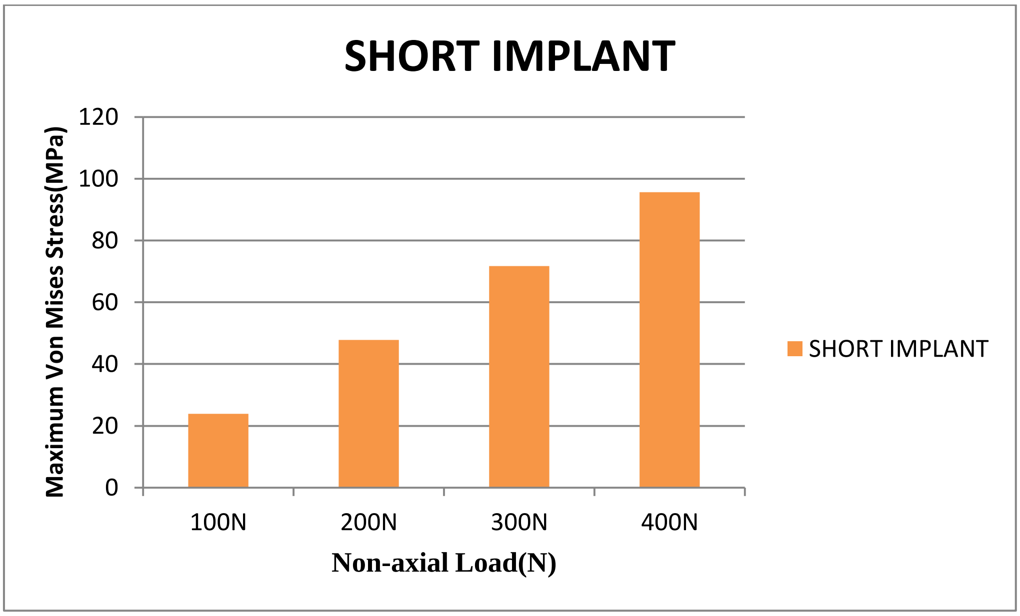

**Graph No: 12-depicting the multiple comparison of Max: Principal stresses in Group II**



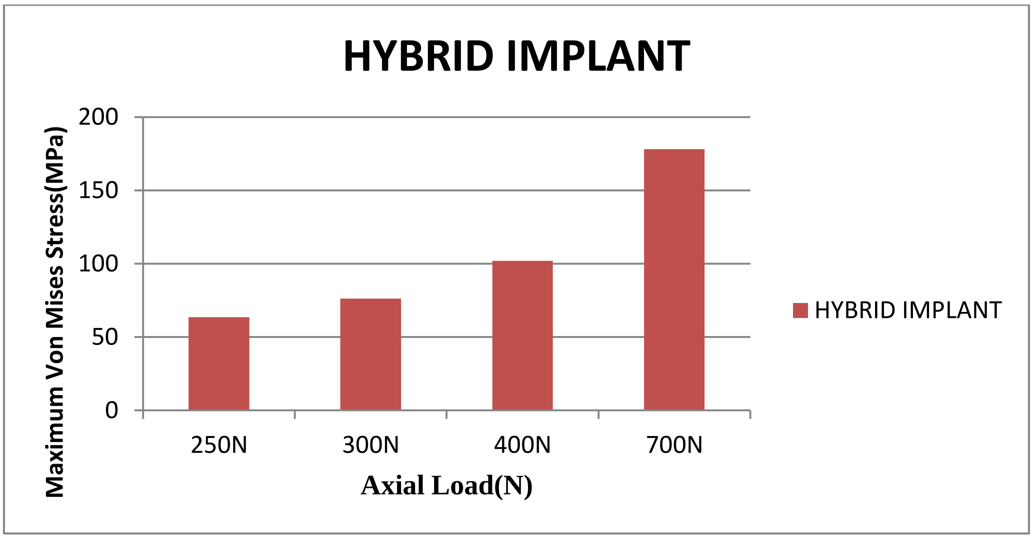
**Graph No:1- depicting Von Mises Stresses for different Axial loads in Short implant**



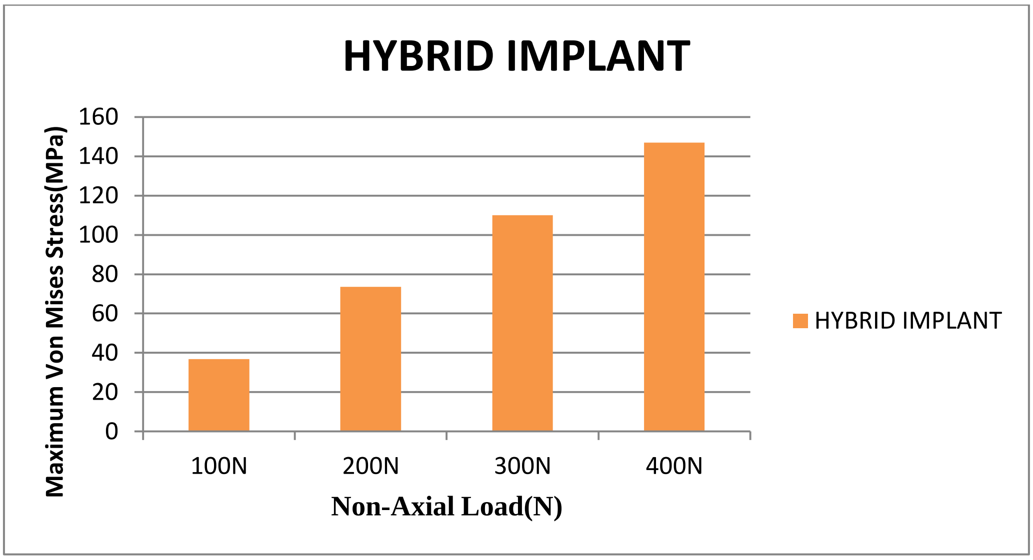

**Graph No:2- depicting Von Mises Stresses on different Non-Axial loads in Short implant**



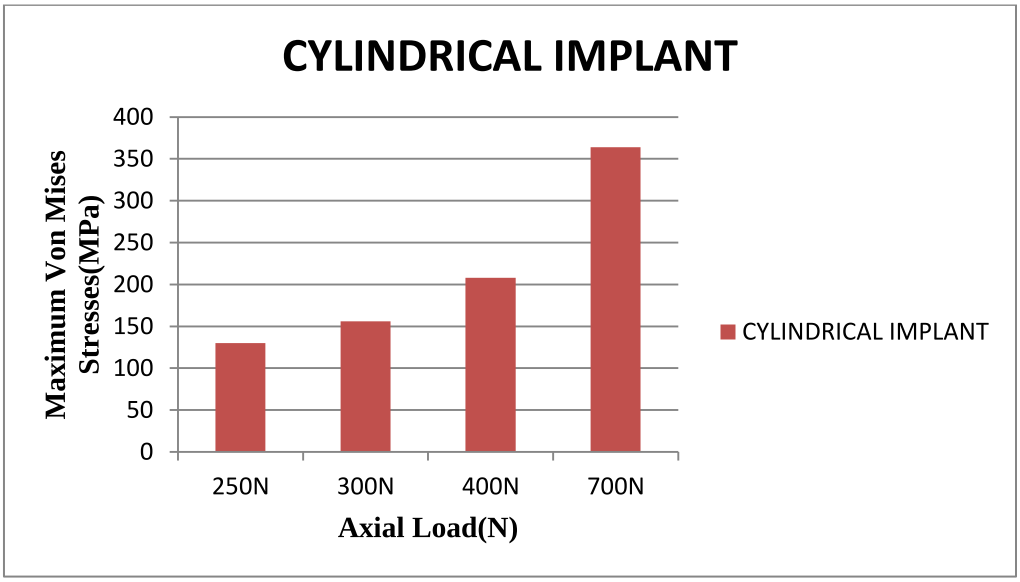
**Graph No:3- depicting Von Mises Stresses for different Axial loads in Hybrid implant**



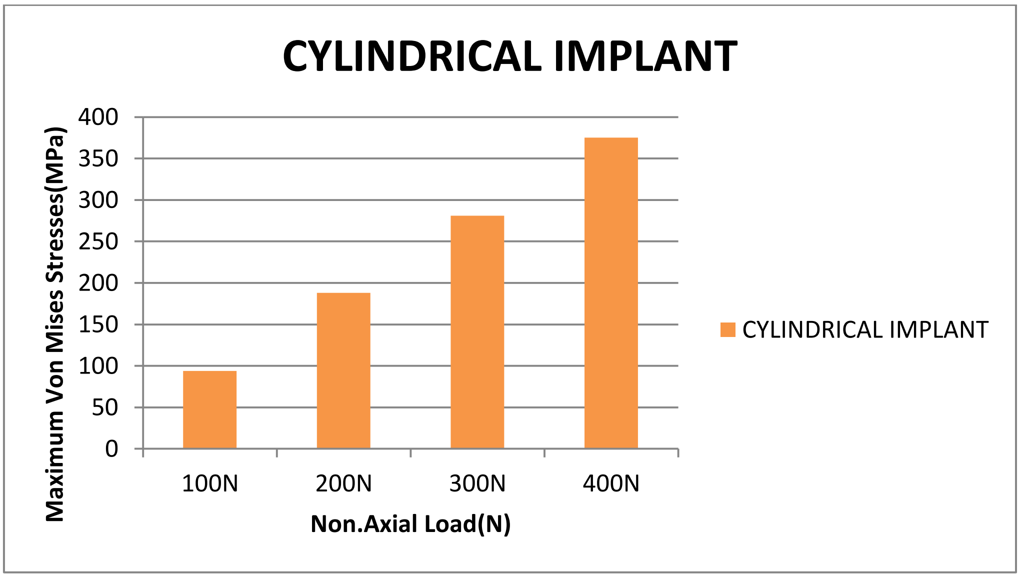

**Graph no:4: depicting Von Mises Stresses for different Non-Axial loads in Hybrid implant**



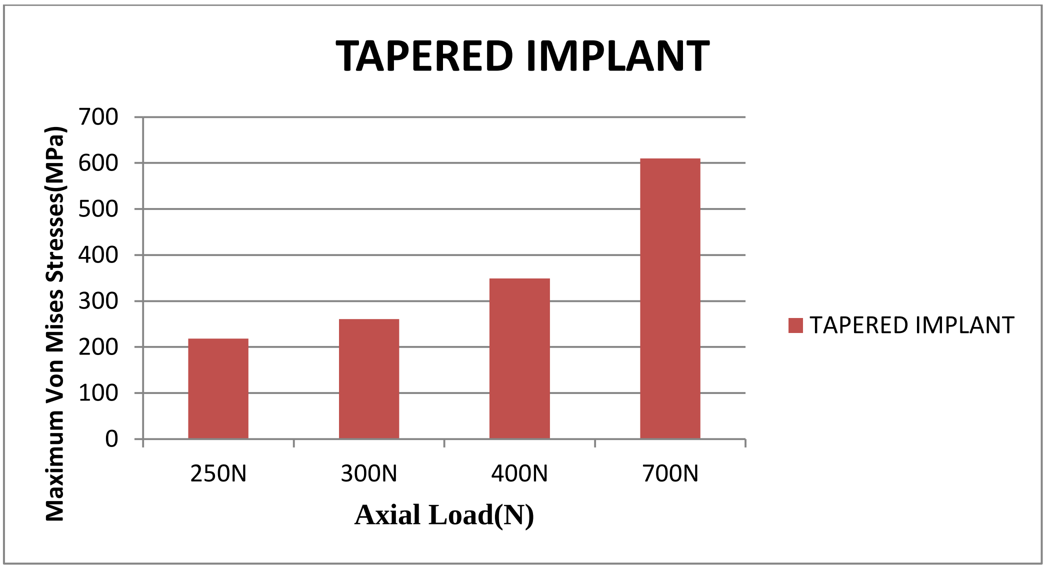
Graph No:5-depicting Von Mises Stresses for different Axial loads in Cylindrical implant



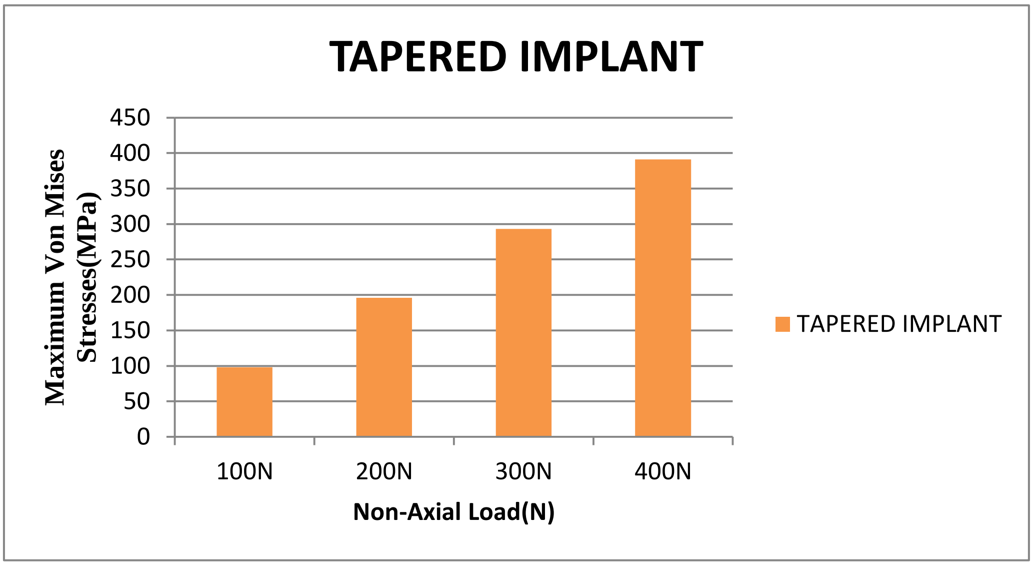

Graph:6: depicting Von Mises Stresses for different non-axial loads in Cylindrical implant



**Graph No:7: Graph depicting Von Mises Stresses for different Axial loads in Tapered implant**




**Graph No:8: depicting Von Mises Stresses for different non-axial loads in tapered implant**



# *DISCUSSION*

Contemporary dentistry is creative as well as therapeutic. Modern dentist aims at rehabilitating the patients form, function and aesthetics of their lost dentition with near resemblance to natural teeth. Rehabilitation of lost teeth can be attained by various methods, which include fixed or removable prosthesis. Fixed dental prosthesis have a number of merits over removable ones, as they can be worn at all times and has better aesthetics, comfort and function when compared to removable prosthesis.

In fixed prosthesis itself there are two types, fixed partial denture and dental implants. Fixed partial dentures have disadvantages like secondary caries to abutment tooth, periodontal problems and most of all the healthy abutments are compromised by tooth preparation for fixation of the prosthesis which gave way to introduction of implants in the field of dentistry. Now-a-days people have become more aware about the merits of dental implants as they are more comfortable and they do not need to be removed. Such an advanced treatment which rehabilitates the lost tooth with proper form, function, aesthetics, comfort, near resemblance to natural teeth and also conserving the adjacent tooth are known as dental implants.

Replacing a missing tooth by dental implants has been carried out since prehistoric period. In ancient Egypt carved seashells and/or stones were placed into human jaws to replace lost teeth. Other examples of early implants were fabricated from noble metals and shaped to resemble natural roots. The first evidence of dental implants is credited to the Mayan population around 600 AD where pieces of shells were used as implants for rehabilitating lost mandibular teeth. Around 800 AD, a stone implant was first fabricated and placed in the lower jaw in the early Honduran culture. Since then many materials have been used to substitute lost teeth like Irido-Platinum, Vitallium etc. It was in 1952 that a physician and professor Per Ingvar Branemark found that Titanium fuses with the bone and he termed that phenomenon as "osseointegration"[59]. Osseointegration can be defined as "the apparent direct attachment or connection of osseous tissue to an inert, alloplastic material without intervening connective tissue"[60]. A dental implant is said to be successful only when it osseointegrates with the surrounding bone.

The Branemark system was introduced in the United States in 1982. These implants were machine surfaced to be a cylindrical screw. Since then, other endosseous implant designs were also introduced but it was popularised recently only. Dental implant according to GPT-8 is defined as "a prosthetic device made of alloplastic material(s) implanted into the oral tissues beneath the mucosal and periosteal layer, or within the bone to provide retention and support for a fixed or removable dental prosthesis.

Various materials are used for the manufacturing of dental implants. An ideal implant material should be biocompatible, with suitable toughness, strength, corrosion, wear and fracture resistance. From a materialistic point of view, dental implants may be made from metals, ceramics or polymers. Material compatibility is the most important matter to be considered for a successful dental implantation. Titanium and its alloys are known to be biocompatible materials so that they are well tolerated by living tissues and capable of promoting osseointegration[61].

Branemark et al started the new era of implantology when they published the findings about Titanium dental implants in 1969. Since then this technique still remains popular and dependable, with only shape and surface of the Titanium implants having changed and excellent biocompatibility of Titanium assures good tissue integration[62].

Titanium alloys of interest to dentistry exist in three structural forms: alpha (α), beta (β) and alpha-beta. The alpha (α) alloys have a hexagonal closely packed (hcp) crystallographic structure, while the beta alloys (β) have a body-centered cubic (bcc) form. These different phases originate when pure titanium is alloyed with elements, such as Aluminium and Vanadium, in definite concentrations and then cooled from the molten state. Titanium has a relatively low density, are strong and highly resistant to fatigue and corrosion. Although they are stiffer than bone, their Modulus of elasticity is closer to bone than any other implant material, with the exception of pure Titanium. This is desirable, as it results in a more favourable stress distribution at the bone-implant interface[63].

The biological fixation between the dental implant and bone should be considered essential for the long-term success of implant-supported prostheses. In this context, the implant design modifications gained a vital and decisive place in implant research over the last few years. As the most explored topic, it led to the development of enhanced dental treatment modalities and the extensive use of dental implants. Nowadays, a large number of implant types with a great variety of designs and other features are commercially available[64].

Various implant designs have been studied and used to favour the mechanism of Osseo integration. This strategy aims at promoting the mechanism of Osseo integration with faster and stronger bone formation, to confer better stability during the healing process, thus allowing more rapid loading of the implant.

The main goal of the development of implant designs are to improve the clinical performance in areas with poor quantity or quality of bone, to accelerate the bone healing and thereby permitting immediate or early loading protocols.

The major factor leading to late failure of implant-supported restorations is inappropriate selection of implants and lack of understanding of biomechanical concepts, According to **Himmlova´ L et al**[11] the decrease in stresses applied by the implant on to the bone was the greatest for implants with larger diameter compared to smaller ones and the influence of implant length and taper was not as pronounced as that of implant diameter.

The Finite Element Analysis is an accepted theoretical technique used in solution of engineering problems and offers many advantages over other methods in considering the complexities that characterize actual clinical situations. Most Finite Element Analysis models assume a state of the optimal osseointegration, meaning that cortical and cancellous bones are assumed to be perfectly bonded to the implant. This does not occur so exactly in clinical situations. However, **Papavasiliou *et al***[10] concluded that the degree of osseointegration had affected only the deflection and did not affect the stress levels or distributions for axial or oblique loads in Finite Element model analysis.

The aim of the present study was to evaluate the stress distribution around four implant designs placed in molar region of mandible. The study consist of two groups each group has a set of four implant designs

1. Model 1: Short implant
2. Model 2: Hybrid implant
3. Model 3: Cylindrical implant
4. Model 4: Tapered implant

In Group I, axial loads of magnitude 250N, 300N, 400N and 700N are applied perpendicular to the long axis of the implant.

In Group II, non-axial loads of magnitude 100N, 200N, 300N and 400N are applied at an angle of 15° to the long axis of the implant.

The maximum Von Mises equivalent stress values and maximum principal stress values were evaluated for the two groups.

## Maximum Von Mises equivalent stresses in Group I:

When an axial load of **250N** was applied onto the implant models the maximum Von Mises value obtained for short implant was **43.5 MPa,** hybrid implant was **63.6 MPa**, cylindrical implant was **130 MPa** and for tapered was **218 MPa**.

On a load of 300N the maximum Von Mises value obtained for short implant was **52.2 MPa**, hybrid implant was **76.3 MPa,** cylindrical implant was **156 MPa** and for tapered implant was **261 MPa.**

On a load of **400N** the maximum Von Mises value obtained for short implant was **69.6 MPa,** hybrid implant was **102 MPa**, cylindrical implant was **208 MPa** and for tapered implant was **349 MPa**.

On a load of **700N** the maximum Von Mises value obtained for short implant was **122 MPa**, hybrid implant was **178 MPa**, cylindrical implant was **364 MPa** and for tapered implant was **610 MPa.**

## Maximum Von Mises equivalent stresses in Group II:

When non-axial load of **100N** was applied at an angle of 15° the maximum Von Mises value obtained for short implant was **23.9 MPa**, hybrid implant was **36.8 MPa,** cylindrical implant was **93.8 MPa** and for tapered implant was **97.8 MPa.**

On a non-axial load of **200N** the maximum Von Mises value obtained for short implant was **47.8 MPa**, hybrid implant was **73.6 MPa**, cylindrical implant was **188 MPa** and for tapered implant was **196 MPa.**

On a non-axial load of **300N** the maximum Von Mises value obtained for short implant was **71.7 MPa**, hybrid implant was **110 MPa**, cylindrical implant was **281 MPa** and for tapered was **293 MPa.**

On a non-axial load of **400N** the maximum Von Mises value obtained for short implant was **95.6 MPa**, hybrid implant was **147 MPa**, cylindrical implant was **375 MPa** and for tapered was **391 MPa**.

## Maximum Principal stresses in Group I:

When an axial load of **250N** was applied onto the implant models the maximum principal stress value obtained for short implant was **15 MPa**, hybrid implant was **21.3 MPa**, cylindrical implant was **49.1 MPa** and for tapered implant was **213MPa**.

On a load of **300N** the maximum principal stress value obtained for short implant was **18 MPa**, hybrid implant was **25.5 MPa**, cylindrical implant was **58.9 MPa** and for tapered implant was **256 MPa**.

On a load of **400N** the maximum principal stress value obtained for short implant was **24 MPa**, hybrid implant was **34 MPa**, cylindrical implant was **78.5 MPa** and for tapered implant was **341 MPa**.

On a load of **700N** the maximum principal stress value obtained for short implant was **42.1 MPa**, hybrid implant was **59.5 MPa**, cylindrical implant was **137 MPa** and for tapered implant was **598 MPa**.

**Maximum principal stresses in Group II:**

When non-axial load of **100N** was applied at an angle of 15° the maximum principal stress value obtained for short implant was **6.02 MPa**, hybrid implant was **5.35 MPa**, cylindrical implant was **36.6 MPa** and for tapered implant was **70.6 MPa**.

On a non-axial load of **200N** the maximum principal stress value obtained for short implant was **12 MPa**, hybrid implant was **10.7 MPa**, cylindrical implant was **73.3 MPa** and for tapered implant was **141 MPa.**

On a non-axial load of **300N** the maximum principal stress value obtained for short implant was **18.1 MPa**, hybrid implant was **16.1 MPa**, cylindrical implant was **110 MPa** and for tapered implant was **212 MPa**.

On a non-axial load of **400N** the maximum principal stress value obtained for short implant was **24.1 MPa**, hybrid implant was **21.4 MPa**, cylindrical implant was **147 MPa** and for tapered implant was **283 MPa.**

When the values of different stresses produced by the implant models in bone where observed they showed great variations, which concurs to the findings of **Siegele D et al (1989)**[2] who stated that different implant shapes lead to significant variations in stress distributions in the bone.

## Comparison of Von Mises stress values in Group I:

- When the Von Mises stress values of short implants and tapered implants were compared in group I, it was observed that the values of Von Mises stresses produced by tapered implants in bone were **5 times** higher than that of short implants.
- When the Von Mises stress values of short implants and cylindrical implants were compared in group I, it was observed that the values of Von Mises stresses produced by cylindrical implants in bone were **3 times** higher than that of short implants.
- When the Von Mises stress values of short implants and hybrid implants were compared in group I, it was observed that the values of Von Mises stresses produced by hybrid implants in bone were **1.5 times** higher than that of short implants.

## Comparison of Von Mises stress values in Group II:

- When the Von Mises stress values of short implants and tapered implants were compared in group II, it was observed that the values of Von Mises stresses produced by tapered implants in bone were **4 times** higher than that of short implants.
- When the Von Mises stress values of short implants and cylindrical implants were compared in group II, it was observed that the values of Von Mises stresses produced by cylindrical implants in bone were **3.9 times** higher than that of short implants.

- When the Von Mises stress values of short implants and hybrid implants were compared in group II, it was observed that the values of Von Mises stresses produced by hybrid implants in bone were **1.5 times** higher than that of short implants.

## Comparison of maximum principal stress values in Group I:

- When the maximum principal stress values of short implants and tapered implants were compared in group I, it was observed that the values of maximum principal stresses produced by tapered implants in bone were **14 times** higher than that of short implants.
- When the maximum principal stress values of short implants and cylindrical implants were compared in group I, it was observed that the values of maximum principal stresses produced by cylindrical implants in bone were **3 times** higher than that of short implants.
- When the maximum principal stress values of short implants and hybrid implants were compared in group I, it was observed that the values of maximum principal stresses produced by hybrid implants in bone were **1.4 times** higher than that of short implants.

## Comparison of maximum principal stress values in Group II:

- When the maximum principal stress values of short implants and tapered implants were compared in group II, it was observed that the values of maximum principal stresses produced by tapered implants in bone were **11 times** higher than that of short implants.

- When the maximum principal stress values of short implants and cylindrical implants were compared in group II, it was observed that the values of maximum principal stresses produced by cylindrical implants in bone were **6 times** higher than that of short implants.
- When the maximum principal stress values of short implants and hybrid implants were compared in group II, it was observed that the values of maximum principal stresses of both implant designs were almost the same.

In Group I and Group II the Von Mises stress values and maximum principal stress values obtained for short implants were the least and for tapered implants were the highest as concluded by **Petrie C S et al in 2005,** [13] who stated that a wide and relatively long, non-tapered implant appears to be the most favorable choice to minimize peri-implant strain in the alveolar bone.

**The present finite element study suggests that implants with wider diameter have more favorable stress distribution in bone compared to longer implant designs.**

**From the values attained it was also observed that the Von Mises stresses and Principal stress values of short implants were the least followed by hybrid and cylindrical implants and the**

**highest values were obtained for tapered implants. This suggests that, the first choice will be short implant and if it is not favorable then hybrid implant will be the next choice followed by cylindrical implant and the last will be tapered implant in order to enhance the stability as well as the survival rate of the implants.**

## Finite element analysis and statistical analysis

In Finite element analysis, since the variables may be manipulated with computer precision, chance variation from sampling error is eliminated. The same Finite element analysis repeated any number of times will yield identical results 100% of times. Thus it is certain that the results are always caused by the manipulation of the variables and not by chance. Hence conventional interferential statistical analysis is not normally included in a Finite element analysis study. But there are different sources of potential error. If key features such us material properties, geometry, interface status, boundary conditions or loading of the real system to be modelled is inaccurately represented, the model may be deficient or incorrect.

## Limitations of Finite element analysis

Finite element analysis has proved to be extremely accurate and precise method for analyzing structures. However, living structures are more than mere objects. Finite Element analysis is based on mathematical calculations based on simulation of the structure in its environment. But living tissues are beyond the confines of set parameters and values i.e. biology is not a computable entity. Therefore although Finite Element analysis provides a very sound theoretical basis of understanding the behavior of a structure in a given environment, it should not be considered alone. Actual experimental techniques and clinical trials should follow the finite element analysis to establish the true nature of biologic system.

In conclusion it must be emphasized that these results were obtained through a mathematical model, which cannot fully represent the complexity of the biologic field. These results can only be used as an initial guideline to further in-vitro stress analysis followed by clinical trials.

# *SUMMARY AND CONCLUSION*

The present study used three dimensional finite element method to analyze the stress distribution around four different implant designs placed in mandibular molar region under axial and non-axial loads.

A three dimensional finite element model of the mandible with four different implant designs were modelled using modelling software 'Solidworks' and was analyzed for stresses produced in the bone following axial and non-axial biting loads of different magnitude using analyzing software 'ANSYS Workbench'.

The results of the study indicated that implants with wider diameter have more favorable stress distribution in bone compared to longer implant designs and influence of implant length and taper was not as pronounced as that of implant diameter.

Within the limits of the present study it can be concluded that:

1. Different implant shapes lead to significant variations in stress distributions in the bone.
2. The Von Mises stresses in and around tapered implant was 5 times higher than that of short implants during axial loading and 4 times higher during non-axial loading.
3. The Von Mises stresses in and around cylindrical implant was 3 times higher than that of short implants and 3.9 times higher during non-axial loading.

4. The Von Mises stresses in and around hybrid implant was 1.5 times higher than that of short implants during both axial and non-axial loading.
5. The maximum principal stresses in and around tapered implant was 14 times higher than that of short implants during axial loading and11 times higher during non-axial loading.
6. The maximum principal stresses in and around cylindrical implant was 3 times higher than that of short implants during axial loading and 6 times higher during non-axial loading.
7. The maximum principal stresses in and around hybrid implant was 1.4 times higher than that of short implants during axial loading and almost the same during non-axial loading.
8. The implants with wider diameter have more favorable stress distribution in bone compared to longer implant designs.
9. The influence of implant length and taper was not as pronounced as that of implant diameter.
10. Short diameter implants are better in stress distribution compared to long implants and could be considered for use with fixed restorations and mandibular over dentures.
11. The first choice will be short implant and if it is not favorable then hybrid implant will be the next choice followed by cylindrical implant and the last will be tapered implant in order to enhance the stability as well as the survival rate of the implants.

12. Use of wider diameter implants enhances the stability and gives more durability to the implant thereby increasing the survival rates.

Computer modeling, such as finite element method, offers many advantages over other techniques of stress analysis. However, the assumptions and limitations of the method must be acknowledged.

**It was observed that the Von Mises stresses and Principal stress values of short implants were the least followed by hybrid and cylindrical implants and the highest were obtained for tapered implants. This suggests that, the first choice will be short implant and if it is not favorable then hybrid implant will be the next choice followed by cylindrical and tapered implant in order to enhance the stability as well as the survival rate.**

**Based on the observations of the present study, it was concluded that short implants with wider diameter have more favorable stress distribution compared to longer implants. So if we consider the longevity of the implant then short implants can be considered as a better treatment option when there is adequate bone width for fixed restorations as well as for overdentures. Long implants are indicated only in conditions like severely atrophied bone having inadequate bone width.**

However further clinical research is suggested in order to prove it as a reliable and successful treatment modality.

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